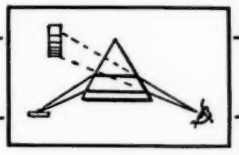
Journal of the OPTICAL SOCIETY *of* AMERICA

VOLUME 30
NO. 4



APRIL
1940

Editorial Comment 141

Aniseikonia . . . . . GORDON H. GLIDDON 142

Induced Size Effect . . . . . KENNETH N. OGLE 145

United States Color Standards for Rosin . . . . . BROOKS A. BRICE 152

Hue Sensibility to Dominant Wave-Length Change and the Relation Between Saturation and Colorimetric Purity . . . . . DOROTHY NICKERSON AND WALTER C. GRANVILLE 159

Fluorescent Mercury-Vapor Lamp as a Light Source for a Single-Point Check on Optical Pyrometers . . . . . C. F. LUCKS AND H. W. RUSSELL 163

Visibility Through Haze and Smoke, and a Visibility Meter . . . . . G. D. SHALLENBERGER AND E. M. LITTLE 168

Doctor August Herman Pfund, Ives Medalist for 1939 . . A. G. WORTHING 177

Published monthly
at Prince and Lemon Sts., Lancaster, Pa.
by the
AMERICAN INSTITUTE OF PHYSICS
Incorporated
175 Fifth Avenue, New York, N. Y.
FOR AND UNDER THE EDITORIAL SUPERVISION OF
THE OPTICAL SOCIETY OF AMERICA

BOSTON UNIVERSITY
COLLEGE OF LIBERAL ARTS
LIBRARY

THE OPTICAL SOCIETY OF AMERICA

Officers of the Society

K. S. GIBSON, *President*
National Bureau of Standards
Washington, D. C.

A. G. WORTHING, *Vice President*
University of Pittsburgh
Pittsburgh, Pennsylvania

ARTHUR C. HARDY, *Secretary*
Massachusetts Institute of Technology
Cambridge, Massachusetts

HENRY F. KURTZ, *Treasurer*
Bausch & Lomb Optical Company
Rochester, New York

The Board of Directors consists of the above officers; the Editor of the Journal; the Past President; and five directors-at-large.

R. C. GIBBS, *Past President*
Cornell University
Ithaca, New York

GEORGE R. HARRISON, *Editor*
Massachusetts Institute of Technology
Cambridge, Massachusetts

Directors-at-Large

J. W. BEAMS
University of Virginia
Charlottesville, Virginia

H. P. GAGE
Corning Glass Works
Corning, New York

RUDOLF KINGSLAKE
Eastman Kodak Company
Rochester, New York

WILLIAM F. MEGGERS
National Bureau of Standards
Washington, D. C.

BRIAN O'BRIEN
University of Rochester
Rochester, New York

Rochester, New York, Section of the Optical Society of America

R. E. BURROUGHS, *President* B. O'BRIEN, *Vice President* D. L. MACADAM, *Secretary* J. W. GILLON, *Treasurer*
Councillors: J. W. FORREST, R. KINGSLAKE, W. B. RAYTON, J. H. WEBB, A. A. COOK (*ex officio*)

Corporation Members of the Optical Society of America

AMERICAN OPTICAL COMPANY, Southbridge, Massachusetts
BAUSCH & LOMB OPTICAL COMPANY, Rochester, New York
BELL TELEPHONE LABORATORIES, INC., New York, New York
CORNING GLASS WORKS, Corning, New York
GAERTNER SCIENTIFIC CORPORATION, Chicago, Illinois
INTERCHEMICAL CORPORATION, New York, New York
KEUFFEL & ESSER COMPANY, Hoboken, New Jersey
SPENCER LENS COMPANY, Buffalo, New York
ARTHUR H. THOMAS COMPANY, Philadelphia, Pennsylvania

THE OPTICAL SOCIETY OF AMERICA was organized in 1916 "*to increase and diffuse the knowledge of optics in all its branches, pure and applied, to promote the mutual interests of investigators of optical problems, of designers, manufacturers and users of optical instruments and apparatus of all kinds and to encourage cooperation among them.*" It aims to serve the interests of all who are engaged in any branch of optics from fundamental research to the manufacture of optical goods.

MEMBERSHIP

Regular Members: "Any person who has contributed materially to the advancement of optics is eligible for regular membership."

Associate Members: "Any person who is interested in optics is eligible for associate membership."

Corporate Members: "Any corporation desirous of encouraging the work of the Society is eligible for corporation membership"

The Society cordially invites to membership all who are interested in any branch of optics, either in research, in instruction, in optical or illuminating engineering, in the manufacture and distribution of optical goods of all kinds or in physiological and medical optics.

ANNUAL DUES

Regular members, $7.50; Associate members, $5.00; Corporate members, $50.00. These dues include subscription to the Society's official journal, the *Journal of the Optical Society of America.*

MEETINGS

The Society holds two meetings per year: An annual meeting in the autumn and a midwinter meeting jointly with the American Physical Society.

For further information concerning the Optical Society of America address the Secretary, Professor Arthur C. Hardy, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Journal of the
OPTICAL SOCIETY *of* AMERICA

VOLUME 30 APRIL, 1940 NUMBER 4

Editorial Comment

THE NEW OPTICS

WHAT limitations should be set on the character of papers to be published in an optical journal? For editorial purposes, optics is "the science which deals with radiant energy, its genesis, its propagation, the effects which it suffers, the effects which it produces, and all phenomena closely associated with it."

A committee of astronomers once officially recorded its lack of interest in light of wavelengths shorter than 2900A—obviously no information about the stars and the heavens would ever be brought by light which could not penetrate the earth's atmosphere! A few years later these same astronomers had cause hastily to extend the limits of their interest, when the brilliant work of Bowen and others showed that many previously unidentified spectrum lines, packed with useful information about stars and nebulae, arose from atomic transitions made evident only by study with the vacuum spectrograph of light of extremely short wave-lengths.

Similarly, practical-minded manufacturers of lamps for home and street lighting now find themselves supporting researches designed to further the efficient production of their old bugbear, invisible light, which they have now learned to make visible through flourescence. So also television-tube designers are involved in theoretical investigations into the mechanism of electro-luminescence and the theory of the solid state. The old idea that the only radiation important to the eye is radiation which it can see has long since been outmoded.

The Optical Society of America has wisely defined optics very broadly, and the editors of this journal welcome contributions involving any phenomenon falling within the definition given above. X-rays, electron diffraction, infra-red or ultraviolet radiation, or the spectroscopy of waves of any length between a fraction of an angstrom and many thousands of angstroms, are topics no less suitable for papers on modern optics than are color and vision. The boundaries of any field of learning must be kept flexible, for the principle value of an artificial boundary lies in the indication of progress which its movement gives.

THANKS WHERE DUE

During the interim between the incumbency of Professor F. K. Richtmyer, late editor, and the appointment of a new editor, the affairs of the Journal would have become sadly confused had not several members and supporters of the Optical Society come ably to its assistance on short notice. Professors R. C. Gibbs and L. G. Parratt of Cornell University undertook immediate direction of journal affairs, and handled efficiently the editing and routing of manuscripts. Professor A. G. Worthing of the University of Pittsburgh, as Chairman of the Program Committee, arranged for the publication and editing of the invited papers presented at the Lake Placid Symposium. Miss C. M. Terry, for many years secretary to the editor, continued the handling of journal copy and correspondence in her usual efficient manner, and has since furnished invaluable aid to the new editor in acquainting him with journal affairs. This loyal assistance is gratefully acknowledged.

BOSTON UNIVERSITY
COLLEGE OF LIBERAL ARTS
LIBRARY

Aniseikonia*

GORDON H. GLIDDON
Dartmouth Eye Institute, Dartmouth Medical School, Hanover, New Hampshire
(Received January 15, 1940)

ANISEIKONIA[1, 2] is that condition in which the ocular images are unequal in size and/or shape. The term "ocular image" is used to describe the impression which reaches consciousness through the vision of one eye. It is determined not only by the properties of the dioptric image that is formed on the retina of the eye, but also by the modifications imposed upon that image by the anatomical properties and physiological processes by which this image is carried to the higher brain centers. Iseikonia, then, is the condition in which the size and shape of the ocular images are the same. Aniseikonic differences can be measured by means of an ophthalmoeikonometer. The lenses which correct the condition of aniseikonia are called aniseikonic lenses, and they are lenses with a specified refractive power and magnification.[3, 4] The American Optical Company has done a splendid job in the manufacture of these rather complicated lenses, many of which are in the form of bitorics with rather steep curves on both surfaces.

The clinical aspects have been dealt with rather completely in the publication in the *Archives of Ophthalmology*,[5, 6] and the *American Journal of Optometry*.[7, 8]

There are many people who have symptoms associated with the use of their eyes which cannot be accounted for by the ordinary ocular defects. They often complain of headaches, dizziness or nervousness. They may be bothered by bright lights (photophobia), or may complain of excessive tiring of the eyes. They may experience difficulty when riding in the train or auto, or when in the movies. Some complain of a burning or itching of the eyes; others get sleepy after reading for a short time. There is a possibility that such individuals may have aniseikonia. It has been found that the average individual without symptoms probably has about 0.50 percent of aniseikonia—the threshold is about 0.25 percent and in some cases where the vision is extremely good, may be as low as 0.10 percent. The average amount usually found in the case of patients with symptoms is 1.75 percent, and some patients may have 3.00 or 4.00 percent. The actual amount of aniseikonia in itself does not tell us anything, for different individuals have different ways of tolerating or compensating for it. Certain cross-eyed individuals may have differences of ten or fifteen percent, but in such cases most of their seeing is done with one eye. In general, one might say that if a person has been properly corrected for his refractive error and still does not have comfortable vision, there is another factor which may be the cause of some of the patient's trouble. Any aniseikonia present should be measured and corrected to see how much of a factor it really is in the individual's case.

The second problem which I wish to consider is that of reading disability. Many of you are doubtless aware that this problem has been occupying a large amount of the time of educators and psychologists in the last few years. We were first introduced to the problem when some of the students at Dartmouth were sent to us because they were failing in their studies, in spite of the fact that they seemed intelligent enough to handle their work satisfactorily. We found that

* Presented by invitation at the meeting of the Optical Society of America, Lake Placid, New York, October 13, 1939.

[1] A. Ames, Jr., Gordon H. Gliddon and Kenneth N. Ogle, "Size and Shape of Ocular Images. I. Methods of Determination and Physiologic Significance," Arch. Ophthalm. **7**, 576–597 (1932).

[2] A. Ames, Jr., Gordon H. Gliddon and Kennth N. Ogle, "The Importance of the Relative Size and Shape of Ocular Images in Vision," Ann. Distinguished Serv. Found. Optom. (1932).

[3] A. Ames, Jr., Gordon H. Gliddon and Kenneth N. Ogle, "Lenses for Changing the Size and Shape of Dioptric Images," Ann. Distinguished Serv. Found. Optom. (1932).

[4] Kenneth N. Ogle, "The Correction of Aniseikonia with Ophthalmic Lenses," J. Opt. Soc. Am. **26**, 323 (1936).

[5] E. H. Carleton and Leo F. Madigan, "Size and Shape of Ocular Images. II. Clinical Significance," Arch. Ophthalm. **7**, 720–738 (1932).

[6] E. H. Carleton and Leo F. Madigan, "Relationships between Aniseikonia and Ametropia. From a Statistical Study of Cases," Arch. Ophthalm. **18**, 237–247 (1937).

[7] Leo F. Madigan and E. H. Carleton, "A Clinical Report of the Corrections of Differences in the Size and Shape of Ocular Images," Ann. Distinguished Serv. Found. Optom. (1932).

[8] Robert E. Bannon, "Heterophoria and Aniseikonia," Am. J. Optom. **16**, March (1939).

certain of these students had eye conditions, either simple refractive or aniseikonic errors, which were not corrected and which, in some cases, seemed to interfere with the students' speed of reading, and in others with their ability to concentrate. When the visual errors of these students were corrected they showed a marked improvement in their scholastic work and, in some cases, they were able to graduate with their class. About 1929 Dr. Walter Dearborn of the Department of Educational Psychology at Harvard University became interested in the work which we were doing, and sent us a number of his problem children to see if their eye condition might be a factor. We found that in many of these cases the correction of the eye defect helped them not only in their school work, but also in their adjustment to their environment. The interest in this phase of the work grew so that in 1934 it was necessary to add to our staff Dr. Henry Imus, who was especially trained in this field of work and who has been spending most of his time on this particular problem. The preparatory schools of the East, as well as the elementary schools, all want to know just how great a factor the eye condition of the individual is in his ability to meet his scholastic requirements. Dartmouth College became interested in this problem and, in 1936, added to the faculty a man who spends his full time helping those students in the college who are having difficulty with their reading. A survey of the freshman class was started to see if the answer to this most interesting problem in education could be found. A preliminary report on this work was published in 1938,[9] and it is planned to have the final report ready some time in 1941. It is hoped that this report will show the relationships between physiological defects of the individual and his scholastic aptitude, and to answer such questions as: "Should the individual be in College," and "What are his chances of getting the most out of college?" This is indeed a new field in education of the greatest importance and one which needs to be studied and analyzed very thoroughly.

The last part of this paper deals with the work of space perception, especially as affected by incongruities of the ocular images. It is common knowledge that many people have difficulty in getting adjusted to their glasses. We know that many other people have trouble when they wear a full correction of their astigmatism for the first time, and the effects are particularly bothersome if the cylinders are at an oblique axis. We first became interested in this problem at Dartmouth around 1930, but it was not until 1934 that we were able to study it at all intensively. Our approach to it at that time was by means of the horopter device and the so-called "tilting field," a horizontal plane constructed with most of the perspective cues removed from view. An individual is asked to set this horizontal plane in a position that seems to him horizontal when viewed with both eyes. Aniseikonic lenses are placed before the eyes and the amount of tipping of the plane plotted against the magnification of the lenses used. The results of this study were published in the *American Journal of Ophthalmology* in 1933.[10] Investigations with these instruments show that when we increase the size of the ocular image in one eye artificially, our spatial localization is affected materially. From 1935 on much work has been done in trying to determine the laws underlying these phenomena.

For a more thorough study of these spatial phenomena enclosed spaces are most helpful. The effects resulting from a room completely covered with leaves, so that most of the cues to monocular perspective are removed, are most interesting. When certain aniseikonic lenses are placed before one eye, to persons with normal binocular vision the room will appear to go out of shape in various ways, depending upon the lenses that are used. In general, a person viewing the leaf room through these glasses will be unable properly to orient himself; the floor of the room may appear to be raised, even as far as one's waist, or pushed away so that it seems far below one, or one may get the impression of being moved nearer to, or farther away from the side walls. If sufficient perspective cues, such as rectilinear forms, are placed in this room the

[9] Henry A. Imus, John W. M. Rothney and R. M. Bear, "An Evaluation of Visual Factors in Reading," Dartmouth College Publications (1938).

[10] Adelbert Ames, Jr., "Aniseikonia—A Factor in the Functioning of Vision," Am. J. Ophthalm. **18**, November (1935).

effects tend to disappear, for here the monocular cues dominate and the brain probably suppresses the cues normally used in binocular vision. These different anomalous spatial effects can be thoroughly appreciated only if they are experienced. (These effects were demonstrated after the meeting.)

In general, the investigations indicate that we have, so to speak, two types of vision: monocular, in which so-called perspective is the basis for spatial localization, and binocular, in which the disparities of the two ocular images are the basis. If there is no aniseikonia, our monocular and binocular cues are in agreement. But if there is a difference between the ocular images there will be a conflict between our orientation in space as told us by our monocular vision, and our orientation in space as told us by our binocular vision. Such a conflict may very well be a factor in the development of a nervous condition in an individual. There are definite implications that aniseikonia may be responsible for certain difficulties experienced in automobile driving and aviation.

The Induced Size Effect*

KENNETH N. OGLE
Division of Research in Physiological Optics, the Dartmouth Eye Institute, Dartmouth Medical School, Hanover, New Hampshire

(Received January 15, 1940)

ONE aspect in studying the importance of the relative sizes of the ocular images of the two eyes in the functioning of binocular vision is to investigate the influence of image size changes upon binocular space perception. There are many ramifications to such a study and it is only possible in this paper to describe one rather important and interesting phase which leads farther than the falsification of space. Since this is a recent development, some of the conclusions given here are purely of a preliminary nature.

It is well first to describe briefly the so-called *size lenses* used to change the relative sizes of the images.[1] In Fig. 1, the general form of the lens is illustrated. It is so designed that the refractive power of the surface toward the object is offset by the refractive power of the surface of the lens toward the eye, so that the image of the object formed by the lens is situated at the position of the object itself. Such a lens can be designed to be correct for only one object distance. At the same time the apparent size of the object is magnified. The amount of the magnification depends upon the refractive power of the front surface and the thickness of the lens, thus a lens having a magnification of 1.04 or 4 percent for a visual distance of 75 cm may have a front surface power of +11.82 diopters (radius=44 mm), a thickness of about 4.7 mm, and a back surface power of −12.16 diopters (radius=−43 mm). In most of the experiments described here the surfaces of the size lenses were ground as *cylinders*, with parallel axes so that the lenses would have a magnification larger than unity in one meridian but unit magnification in the meridian at right angles to the first. These particular lenses have been designated meridional size lenses since they have magnification in one meridion only.

In order that the essential phenomenon of the induced size effect will be clear, it is necessary first to have in mind a simpler but related phenomenon. Consider the diagram in Fig. 2 in which the eyes are shown schematically converged to a point F on a plane, on which there are two other points P and Q seen in indirect vision. Suppose now that a meridional size lens, which magnifies only in the horizontal meridian, is placed before the right eye. Since the size lens magnifies the image in the right eye, the image of P in that eye will appear farther to the right. The position of the stereoscopic image will then correspond to the disparities of a point P'. Likewise, the image of Q, in the right eye will appear farther to the left and the apparent position of the stereoscopic image will correspond to the point Q'. Thus, the whole plane, because of the size lens, will appear as if rotated about the point of fixation. This falsification of the positions of points in space is obviously a phenomenon of geometrical optics. Accordingly, for example, the magnitude of the apparent rotation of the plane can be derived from analytical geometry, with the result:

$$\tan\phi=\frac{M-1}{M+1}\frac{b}{a},$$

where M is the magnification of the lens; b is the visual distance; and a is $\frac{1}{2}$ the interpupillary distance. For a given magnification, the apparent rotation increases as the visual distance increases, and the apparent rotation decreases as the interpupillary distance increases. Also to be noticed is the apparent increase in the distance FP and the apparent decrease in the distance FQ. Thus, besides the apparent rotation, there is an apparent enlargement of distances on the side of the increased image and an apparent diminution of distances on the side of the smaller image.

Experiment has verified this apparent rotation except under conditions where the observer was

* Invited paper read before the Optical Society of America at Lake Placid, New York, October 12, 1939.

[1] For an exact description of these lenses see, K. N. Ogle, "The Correction of Aniseikonia with Ophthalmic Lenses," J. Opt. Soc. Am. **26**, 323–337 (1936).

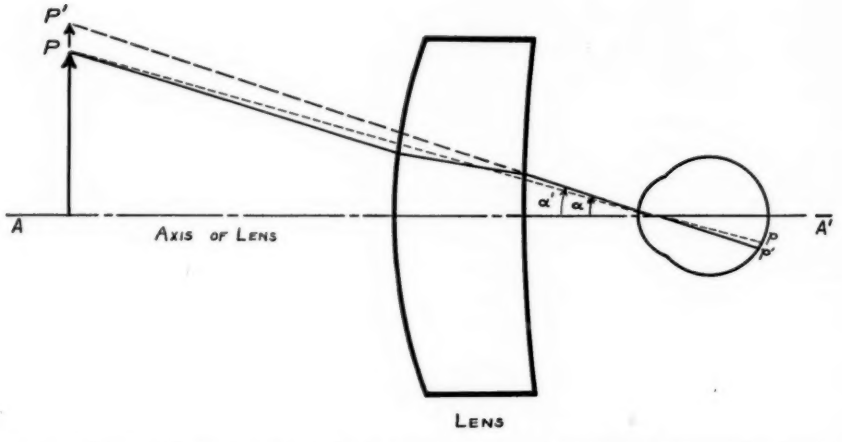


FIG. 1. Schematic diagram of the so-called "size" lens used for introducing differences between the relative sizes of the images of the two eyes.

strongly influenced by perspective and other empirical factors, and then the magnitude of the rotation may be decreased. A person wearing a size lens finds the ground upon which he is walking tipped as though he were walking upon the side of a hill. The sensitivity of the observer to stereoscopic stimuli also is a factor which affects the amount of the apparent rotation. For very distant vision, the apparent rotation should theoretically be large, actually it may not appear at all unless many stereoscopic objects are included in the field of view, and the perspective features are not predominant. This general phenomenon is a geometrical effect and is one that might be expected.

The induced size effect is another phenomenon in which a falsification of the position of objects in space takes place with a size lens before one eye, but in which no such geometrical interpretation can be given. If the meridional size lens magnification takes place only in the *vertical* meridian, a falsification of the binocular visual field also takes place in that objects again appear as though rotated about the point of fixation. Here, however, the apparent rotation is in the direction opposite to that of the geometrical effect described above. In the case of the geometrical effect, the space falsification could be directly attributable to changes in the disparities of the images of objects in space, in the two eyes, in the meridian of stereoscopic depth perception. This is not so in the case of the induced size effect for it has been pretty well established that no depth localization results from vertical disparities of the retinal images of the two eyes of points in space. The apparent rotation in this phenomenon cannot, therefore, be explained by a simple geometrical interpretation as was given above. Moreover, there appears to be no visual functional basis upon which it could depend. The induced effect has been subject to considerable experimentation, and while its exact basis is not yet known, the general facts concerning it have been ascertained.[2, 3]

Using the apparatus which is shown diagrammatically, in Fig. 3, quantitative data concerning both the geometrical and induced effects can be obtained. A test plane is arranged so that it can be rotated about a vertical axis by an observer whose head is supported by a chin cup and forehead rests. A suitable shield before the eyes restricts the view to the plane. Beyond the test plane a large evenly illuminated sheet of white

[2] A. Ames, Jr., "Aniseikonia: A Factor in the Functioning of Vision," Am. J. Ophthalm. **18**, 1014 (1935).

[3] Kenneth N. Ogle, "Induced Size Effect. I. A New Phenomenon in Binocular Space Perception Associated with the Relative Sizes of the Images of the Two Eyes," Arch. Ophthalm. **20**, 604–623 (1938); II. An Experimental Study of the Phenomenon with Restricted Fusion Stimuli, *ibid.* **21**, 604–625 (1939); III. A Study of the Phenomenon as influenced by Horizontal Disparity of the Fusion Contours, *ibid.* **22**, 613–635 (1939); Induced Size Effect with the Eyes in Asymmetric Convergence, *ibid.* (in press).

cardboard serves as a background. Upon the test plane a pattern is drawn with black paint.

The observer is asked to adjust the plane so that it appears parallel to his frontal plane, that is, since the eyes are in symmetrical convergence, normal to his subjective direction of fixation point. By means of a suitable scale, the rotational position of the plane from the true frontal position can be recorded by an assistant. When a meridional size lens is placed before one eye, the plane will have to be rotated considerably in order for it to appear normal again. This rotation is a measure of the apparent rotation caused by the size lens.

With a sequence of meridional size lenses before one eye and then the other with magnification properties first in the horizontal and then the vertical meridians, data for a complete description of the geometrical and induced size effects are obtained. In Fig. 4 a graphical representation of four typical sets of data are shown. The percent magnification of the lens used is plotted on the abscissa, while the degrees of the corresponding rotation are plotted on the ordinate. The geometrical effect is indicated by the data giving a straight line, while the induced effect is indicated by the data giving an elongated sigmoid shaped curve. These graphs strikingly show the difference between the two effects. Since the apparent rotation of the plane for a given difference in the sizes of the images in the vertical meridian is in the direction opposite to that for the difference in the horizontal meridian, the data for the two effects lie in the opposite quadrants of the graph.

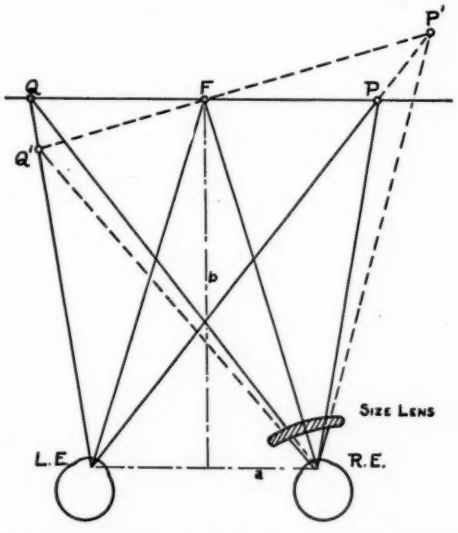


FIG. 2. Illustration of the apparent rotation of a plane (geometrical effect) caused by placing before one eye a meridional size lens which magnifies the image in the horizontal meridian only.

It would be expected that the degree of rotation in the geometrical effect would be nearly

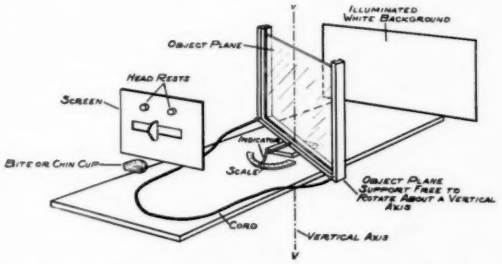


FIG. 3. Schematic drawing of the apparatus used to obtain data showing the geometrical and induced size effects. (Reprinted from the *Archives of Ophthalmology* **20**, 608 (1938).)

proportional to the image size difference for all ordinary values of that difference, since that effect arises solely from the changes of the angular disparities of the images of object points in space caused by the meridional size lens, in the meridian of stereoscopic depth perception. Hence, the data would be expected to lie nearly on a straight line. In the induced effect, however, where no geometrical *interpretation* is directly applicable, the proportionality between the apparent rotation and the image size difference holds only for a central region, beyond which the apparent rotation reaches a maximum and then decreases for higher vertical image size differences. So far as can be ascertained this phenomenon is universal, if the observer has normal binocular vision and stereopsis. It has been measured at visual distances from 20 cm to 3 meters.

The magnitude of the maximum apparent rotations, the image size differences for which the maximum rotations occur, and the slopes of the data lines in the central region (the sensitivities), depend to a certain extent upon the type of pattern employed upon the test plane. An increase in the number of contours on the plane tends to increase all of these factors up to

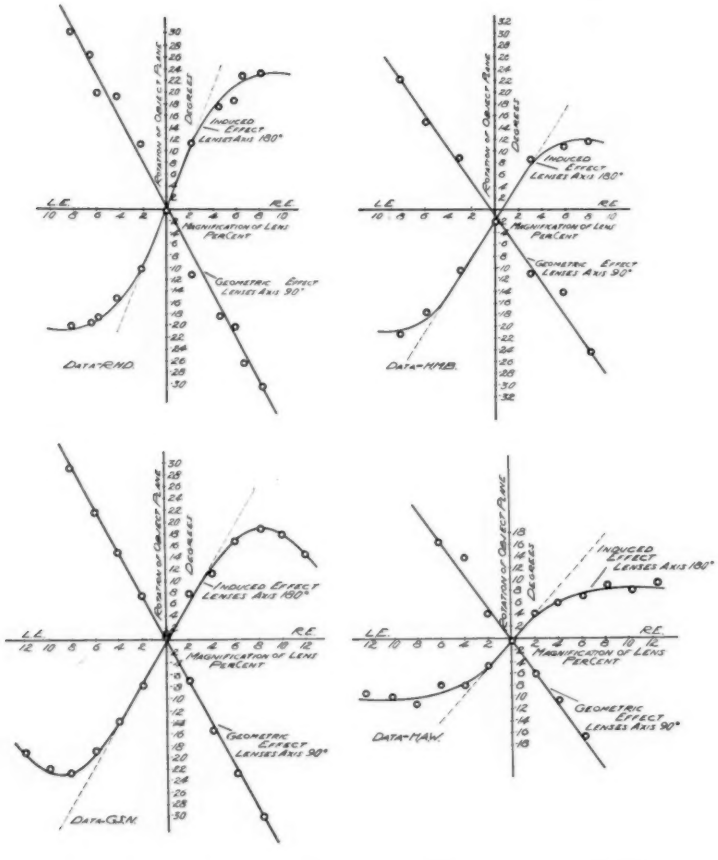


FIG. 4. Graphical representation of typical data for the geometrical and induced size effects. The data are the apparent rotations (in degrees) of the test plane caused by differences in the sizes of the images (in percent) introduced by meridional size lenses before one or the other of the eyes. The visual distance is 40 cm. (Reprinted from the *Archives of Ophthalmology* **20**, 618 (1938).)

definite limits, though variations are found between different observers. The data illustrated in the graphs of Fig. 4 were obtained with a pattern on the test plane consisting of a large number of irregularly scattered dots, placed on both sides of the glass. With this pattern the sensitivities of the two effects are nearly equal, though opposite. The other two factors vary over wide limits between observers. Usually more consistent curves are obtained for the induced size effect if the fusion contours are restricted to relatively small areas above or below the center of the plane. For the principal experiments in the study of the effect, only a horizontal row of irregularly spaced dots provide the necessary points by which the observer judges the orientation of the plane about the vertical axis. Above and below this row of dots suitable larger contours are drawn. On the other hand, if there are no contours above or below the row of small dots, the effect does not occur at all. Thus, for the effect to occur at all, there must be at least two vertically separated contours in the field of vision.

From the large number of sets of data for the induced effect obtained on many different individuals it is believed that the curve which represents a given set is a symmetrical curve.

When the apparent rotations of the induced effect are determined for image size differences up to 20 percent, typical curves obtained are illustrated in Fig. 5. These data were obtained when the only peripheral fusion contours above the horizontal row of scattered dots consisted of small horizontal rectangles. Although the data may become a little more scattered with the higher size differences, especially with a complex pattern on the test plane, the curves describing

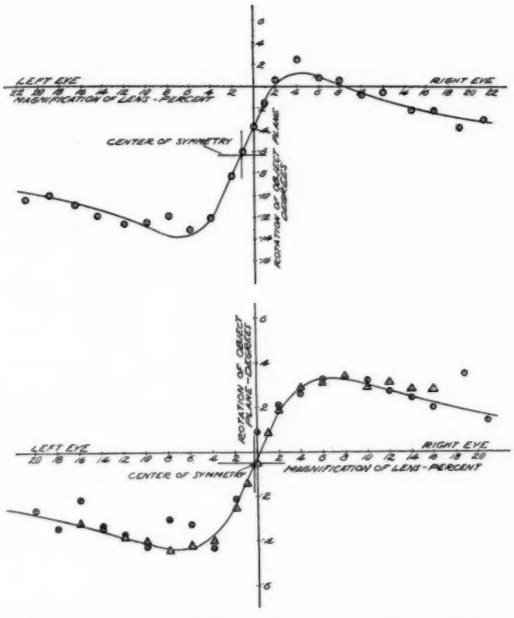


FIG. 5. A graphical illustration of typical sets of data (for K.N.O. [top] and G.S.N.) showing the induced size effect for image size differences out to 20 percent, when the fusion in the vertical meridian is restricted to two separated contours. The visual distance was 40 cm. (Reprinted from the *Archives of Ophthalmology* **21**, 612 (1939).)

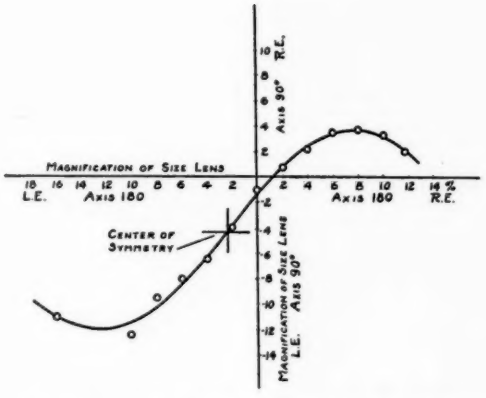


FIG. 7. Graphical illustration of a set of data (K.N.O.), showing the induced size effect curve determined by a "null" method, that is, by off-setting the apparent rotation of the test plane caused by a vertical image size difference by a horizontal size difference to keep the test plane normal.

the data are quite regular. The curve which represents either of these sets of data can be satisfactorily described by the empirical relation $y = Axe^{-B|x|}$, relative to the point of symmetry; where y is the magnitude of the apparent rotation, for a given image size difference x percent; A and B are constants.

If the fusion contours on the test plane are fairly restricted to definite regions, as is the case for the data illustrated above, then x is proportional to the angular retinal image disparity of the images of those contours in the two eyes. See Fig. 6. Thus the effect may be ascribed to an innervation arising from definite vertical retinal image disparities. Upon this basis the experiments could be interpreted to show that the induced effect is associated with the effort to fuse vertically disparate retinal images. This is further suggested by a series of experiments which showed that the sensitivity of the effect decreases exponentially when horizontal disparities are introduced in the images in the two eyes of the peripheral fusion contours seen near the test plane.

The typical sigmoid curve of the induced effect can also be obtained using a "null" method. That is, when a vertical difference in the sizes of the images is introduced between the eyes, one can determine that meridional size lens which placed

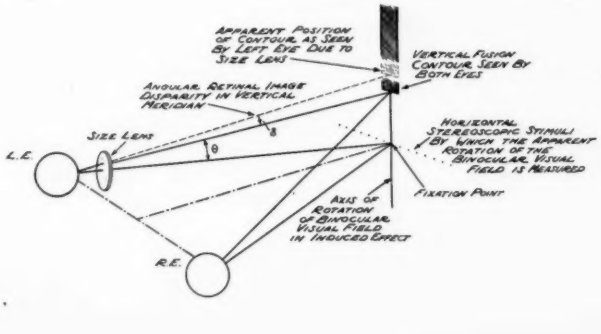

APPARENT POSITION OF CONTOUR AS SEEN BY LEFT EYE DUE TO SIZE LENS
VERTICAL FUSION CONTOUR SEEN BY BOTH EYES
ANGULAR RETINAL IMAGE DISPARITY IN VERTICAL MERIDIAN
SIZE LENS
L.E.
θ
HORIZONTAL STEREOSCOPIC STIMULI BY WHICH THE APPARENT ROTATION OF THE BINOCULAR VISUAL FIELD IS MEASURED
FIXATION POINT
AXIS OF ROTATION OF BINOCULAR VISUAL FIELD IN INDUCED EFFECT
R.E.

FIG. 6. Schematic diagram showing the equivalent vertical angular disparity of the retinal images of peripherally located contours, caused by the difference in the sizes of the images introduced by a size lens. (Reprinted from the *Archives of Ophthalmology* **21**, 613 (1939).)

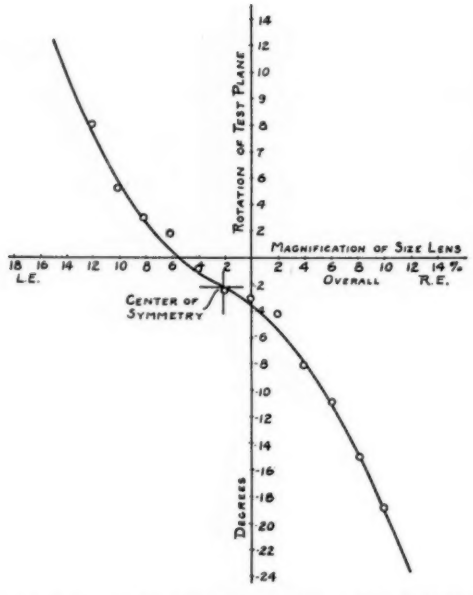


FIG. 8. A graphical illustration of a set of data (K.N.O.) showing the apparent rotation of a test plane caused by using a series of over-all size lenses before the eyes to introduce over-all image size differences. The curve is the resultant of the geometrical and induced size effects.

before one eye to increase the image size in the horizontal meridian keeps the test plane normal. Here the apparent rotation, due to the induced effect (meridional size lens axis 180°) is offset by a geometrical effect (meridional size lens axis 90°). A set of data obtained in this manner is graphically illustrated in Fig. 7. To obtain the points it was usually necessary to determine the horizontal differences which nearly made the plane normal and then interpolate for the difference which actually would make it normal.

Since an over-all size lens will have the same magnification in all meridians, the effect of placing an over-all size lens before one eye upon the apparent position of a test plane should be the combined result of the geometrical and induced effects working against each other. Nevertheless, it would be expected from a study of Fig. 4 that the data on the apparent rotation of the test plane for a sequence of over-all size lenses before one eye and the other would yield a sigmoid curve. A set of data obtained by using over-all size lenses is graphically illustrated in Fig. 8.

The results obtained by these two latter methods of taking data indicate that the sigmoid curve is not the result of empirical factors which limit a normal response to vertical image size differences. They increase the evidence that the effect is the result of a process within the ocular systems, a physiological process or a phenomenon of the higher processes of the brain.

The final aspect of this phenomenon, which will be briefly considered here and which is a current research problem, has to do with a practical application. No doubt it has been noticed in several of the foregoing figures of the induced size effect curves that the center of symmetry of the curve fails to coincide with the origin of the graph. It was apparent that for observers within the research group the position

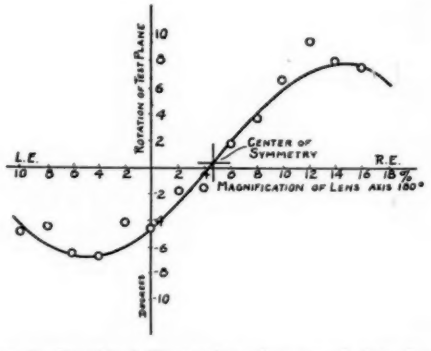


FIG. 9. Graphical illustration of a set of data for the induced effect showing marked displacement of the center of symmetry of the sigmoid curve.

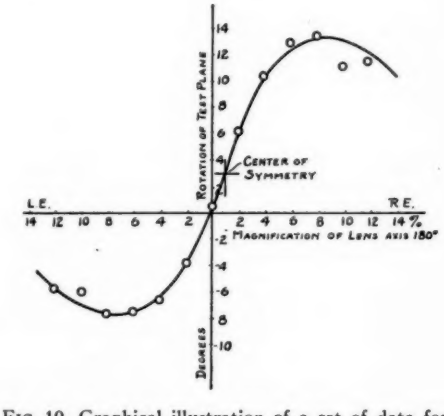


FIG. 10. Graphical illustration of a set of data for the induced effect showing marked displacement of the center of symmetry of the sigmoid curve.

of the point of symmetry was fairly constant irrespective of the test plane pattern or other factors that influence the amplitude of the curve. This seemed to suggest that the phenomenon rests upon a physiological basis and upon a definite anatomical organization of the two visual organs. The displacement then might be an indication of the initial image size difference, and thus might provide a new method for the measurement of aniseikonia. The displacement of the curve horizontally suggests a vertical image size difference. The displacement of the curve vertically may lead to the determination of the horizontal image size difference in terms of the geometrical effect. In Figs. 9 and 10 the data obtained for several patients are graphically illustrated. In the clinic the study of the effect with aniseikonic patients is in the preliminary stage and many factors must be taken into account, before it can be definitely stated that this method is a valid or a practical method of determining aniseikonia.

The United States Color Standards for Rosin

BROOKS A. BRICE
Food and Drug Administration, U. S. Department of Agriculture, Washington, D. C.
(Received January 2, 1940)

The new official United States color standards for grading gum rosin are described and compared with the superseded 1923 Lovibond glass standards. The new standards are made of cemented combinations of Jena and Corning glasses, and show a better spectral match with rosin, higher luminous transmission, more regular spacing of colors on a chromaticity scale, and are more solidly constructed than the old standards. Spectral transmission curves for rosins and the glass standards are shown. The standard colors are specified in terms of the 1931 I.C.I. colorimetric coordinate system with its standard observer and standard illuminant *C*. Chromaticity tolerances are established for duplicate standards.

I. INTRODUCTION

THE grading of gum rosin on the basis of color dates back nearly a century.[1] Gradual improvement in the quality of rosin has required occasional modification of the standards used for grading. In 1914 glass standards, assembled from Lovibond glasses to match the colors of certain so-called "rosin type" samples, were proposed by the U. S. Department of Agriculture and approved by the naval stores industry. These Lovibond glass combinations, with slight modification, were established by the Naval Stores Act of 1923 as the official United States standards for rosin,* for which the letter designations X, WW, WG, N, M, K, I, H, G, F, E, and D, denoting the grades of rosin delimited by these standards, in order of decreasing grade, were given legal status. These standards represented a distinct improvement in permanence of color and uniformity among duplicate sets over the previously used types made of rosin, and did much to remove dissatisfaction with the grading of rosin.

With a view to further improvement of the standards and the grading of rosin a systematic colorimetric investigation has been carried out by the Department of Agriculture in recent years. A preliminary color analysis of the 1923 standards in terms of dominant wave-length, colorimetric purity, and luminous transmission, based on the O.S.A. colorimetric coordinate system and Abbott-Priest sunlight appeared in 1933.[2] In a later publication[3] some improvements possible in the glass standards for rosin were pointed out. This study resulted in the development of more suitable glass standards which, after being approved by the industry, were adopted May 6, 1936 as the official United States standards for rosin under provision of the Naval Stores Act authorizing the modification of existing standards.

The purpose of the present publication is to describe the 1936 standards, compare them with the 1923 standards, and to specify completely their colors in terms of the I.C.I. standard observer and coordinate system.

II. SPECTRAL TRANSMISSION MEASUREMENTS

Selection of suitable colored glass combinations for the new standards and specification of their colors were based on spectral transmission measurements.

An "equal-deflections" method of measurement was used, the apparatus comprising essentially a monochromator (Gaertner L231), an 8.4-volt 4-ampere lamp with its vertical coiled filament imaged symmetrically on the bilateral entrance slit by an achromatic lens, an Archi-

[1] Charles E. Smith, "History of the Development of Naval Stores Inspection and Standards." Naval Stores Rev. **42**, No. 46, 16 (1933); **42**, No. 47, 10 (1933). Drugs, Oils and Paints **48**, No. 3 (1933); **48**, No. 4 (1933). Oil, Paint and Drug Reporter (Feb. 6, Feb. 27, 1933).

* Hereinafter referred to as the "1923 standards."

[2] B. A. Brice, "A Color Analysis of the U.S. Rosin Standards," Naval Stores Rev. **43**, Nos. 5, 6 (1933); American Ink Maker **11**, No. 5, 27 (1933); Drugs, Oils and Paints **48**, No. 4, 136 (1933).

[3] B. A. Brice, "Some Reasons for Modifying the U. S. Rosin Standards," Naval Stores Rev. **43**, No. 30, 6 (1933); Drugs, Oils and Paints **48**, No. 10, 380 (1933); Soap **9**, No. 11, 23 (1933); Paint, Oil, and Chem. Rev. **95**, No. 26, 8 (1933).

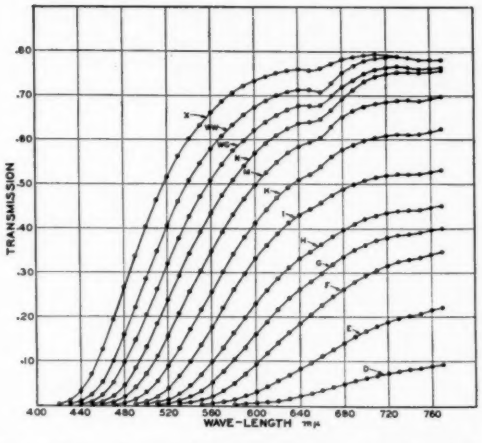


FIG. 1. Spectral transmission curves for gum rosin samples selected to match in color the 1936 glass standards.

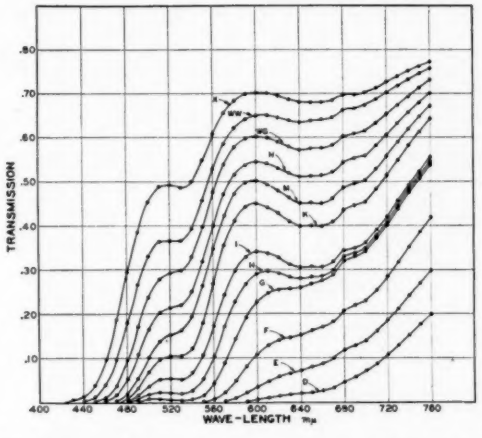


FIG. 2. Spectral transmission curves for the 1923 Lovibond glass standards with clear components removed.

medes spiral sector capable of lateral displacement past the entrance slit; a lens, sample-holder, and blocking-layer photo-cell (Electrocell No. 780) behind the bilateral exit slit, and a galvanometer of sensitivity 2×10^{-10} amp./mm (Leeds and Northrup No. 2500f). The spiral sector $\rho=5.42\theta/\pi$ cm, cut out from $\theta=\pi$ to $\theta=3\pi$ on a milling machine, and rotated at about 180 r.p.m., provided a control on light exposure which was linear with displacement of the spiral, and since the photo-cell as used apparently obeyed Talbot's law, a 100-mm scale to indicate displacement of the sector served as a transmission scale. Measurement of low transmissions was facilitated by inserting in front of the photo-cell wire screens of 18 and 5 percent transmission, calibrated in place in terms of the sector at 10-mμ intervals throughout the spectrum. Samples for transmission measurement were placed on a movable table 25 mm in front of the photo-cell in a parallel light beam having a 10 by 6 mm cross section. Light was diffused over the surface of the photo-cell by a ground glass plate 20 mm in front of the photo-cell. Slit widths of about 4 mμ were used for most of the measurements. A set of filters for reducing stray-light errors was mounted at the exit slit. Frequent checks on the wave-length scale were made.

The reliability of this spectrophotometer was tested by measurements on two colored glass filters standardized by the National Bureau of Standards[4] for spectral transmission. Agreement within the estimated uncertainties of the standard data was obtained except for a few of the low transmissions.

Figure 1 shows spectral-transmission curves for rosin samples of regulation $\frac{7}{8}$ inch thickness, selected to match approximately the 1936 standards in chromaticity. The luminous transmissions were made equivalent by multiplication by the appropriate constant factor. Plane parallel faces were prepared by applying heated pieces of microscope glass slides to the rosin faces or by pouring molten rosin into a metal mold with clamped-on glass windows. The curves show a progressive broadening of light absorption[5] toward longer wave-lengths in going from the yellow X rosin to the red D rosin.

Spectral transmission curves for the 1923 glass standards, in Fig. 2, show the transmission characteristics of combinations of red and yellow Lovibond glasses.[6] For these measurements, the clear components of wavy glass or cellulose acetate films (see Table II), incorporated in

[4] K. S. Gibson, G. K. Walker, M. E. Brown, J. Opt. Soc. Am. **24**, 58 (1934).

[5] The weak absorption band near 650 mμ present in most gum rosins, but not in wood rosins, is probably due to chlorophyll or a derivative. A weak band near 750 mμ is interpreted as an overtone band due to OH vibration in the resin acids.

[6] K. S. Gibson and F. K. Harris, Nat. Bur. Stand. Sci. Paper No. 547 (1927).

these standards to simulate the appearance of a hand-cut rosin sample, were removed. Reliable low transmission values, for example with the F standard from 480 to 550 mμ, were calculated from measurements made on the individual glass components.

Spectral transmission data for the cemented glass combinations comprising the master set (No. 200) of the 1936 standards are given in Table I and plotted in Fig. 3. Low transmission values were calculated from measurements on individual components and on thinner pieces of the same type of glass (see Table II). Calculated and observed transmissions agreed closely wherever a comparison was possible.

Spectral transmission curves for the various types of glass selected for use in the 1936 standards are shown in Fig. 4.

III. Construction and Color Specifications

The 1936 standards are combinations of specially selected Corning and Jena glasses of various thicknesses, as listed in Table II. Ideal glass standards would be made up of different thicknesses of not more than two types of colored glass, selected from melts of high permanence and uniformity of color, and having a close spectral match with well-strained rosin. The glasses selected for the standards X to G are nearly ideal. The amber glass G30B was not used beyond the G standard because in greater thicknesses it no longer gave a good spectral match with rosin. For the F, E, and D standards Corning amethyst glass was combined with sharp spectral cut-off selenium type glasses. The yellow GG9 glass was not needed with the G standard, and its omission effected a smoother

Table I. *Spectral transmission data for the cemented glass combinations comprising set No. 200 of the 1936 U. S. Standards for rosin.*

λ	X	WW	WG	N	M	K	I	H	G	F	E	D
400	0.005	0.001										
410	.006	.0022	0.0008									
420	.0092	.0037	.0015									
430	.0152	.0064	.0026	0.0008								
440	.0311	.0139	.0059	.0020	0.0005							
450	.0595	.0284	.0131	.0048	.0013	0.0002						
460	.106	.0549	.0280	.0114	.0035	.0007						
470	.166	.0926	.0512	.0232	.0083	.0020	0.0003					
480	.234	.143	.0863	.0437	.0181	.0053	.0009					
490	.305	.199	.1305	.0734	.0346	.0119	.0027	0.0003				
500	.373	.260	.181	.1114	.0589	.0239	.0074	.0011	0.0001			
510	.440	.324	.237	.1587	.0932	.0434	.0159	.0033	.0006			
520	.502	.387	.299	.213	.1372	.0730	.0316	.0089	.0020			
530	.556	.450	.363	.273	.190	.1130	.0566	.0200	.0060			
540	.604	.506	.422	.333	.246	.158	.0896	.0373	.0136			
550	.643	.555	.477	.394	.302	.210	.1320	.0635	.0275	0.0004		
560	.673	.595	.526	.447	.358	.264	.178	.0972	.0482	.0099	0.00006	
570	.698	.628	.567	.495	.411	.316	.227	.1357	.0760	.0417	.0034	
580	.713	.651	.597	.533	.454	.363	.272	.174	.1070	.0655	.0149	0.00015
590	.724	.668	.620	.562	.489	.400	.312	.210	.1414	.0840	.0260	.0015
600	.730	.678	.635	.582	.514	.430	.345	.242	.174	.1015	.0354	.0046
610	.729	.683	.642	.594	.530	.449	.368	.265	.200	.1190	.0450	.0078
620	.727	.684	.645	.600	.540	.462	.384	.281	.219	.1358	.0549	.0109
630	.724	.682	.646	.603	.545	.469	.393	.292	.233	.152	.0652	.0142
640	.722	.682	.647	.606	.550	.475	.401	.302	.244	.167	.0750	.0177
650	.723	.683	.650	.610	.555	.482	.408	.309	.253	.181	.0854	.0216
660	.724	.684	.652	.612	.558	.485	.413	.314	.259	.197	.0969	.0266
670	.729	.688	.658	.618	.564	.494	.419	.322	.266	.214	.1099	.0322
680	.738	.698	.667	.628	.573	.504	.428	.331	.270	.234	.1236	.0389
690	.738	.699	.668	.629	.574	.505	.429	.331	.270	.253	.139	.0472
700	.741	.704	.673	.633	.577	.509	.431	.334	.269	.273	.155	.0568
710	.749	.710	.678	.639	.584	.515	.435	.336	.267	.294	.173	.0683
720	.756	.717	.685	.644	.588	.518	.436	.336	.264	.316	.191	.0821
730	.763	.723	.691	.648	.590	.519	.435	.335	.258	.340	.212	.0990
740	.769	.727	.694	.650	.591	.519	.433	.330	.250	.365	.235	.117
750	.773	.731	.696	.651	.590	.516	.428	.324	.240	.390	.258	.139
760	.778	.734	.698	.651	.587	.512	.421	.317	.229	.416	.283	.162

gradation of luminous transmissions for the set of combinations.

All glasses were ground and pitch-polished* to the desired thickness and edge-ground to 20.4 mm square. Combinations were assembled in the order shown in the table by cementing with pale Canada balsam. The purpose of the clear glass component was to make the total thickness of each combination approximately 20 mm. One surface of the clear glass was ground with No. 320 carborundum, and this surface was sealed on the inside of a combination. This gave a slight diffuse appearance to the assembled combination simulating the appearance of molded samples of rosin containing traces of fine dirt. The assembled combinations were finally cemented with Canada balsam into sleeves of German silver tubing $\frac{7}{8}$ inch square outside and $\frac{7}{8}$ inch long. Each metal sleeve was engraved with the proper grade symbol and the number of the set.

The 1923 standards were made up of the Lovibond glasses and clear components listed in Table II, packed into metal sleeves by means of rubber gaskets without cementing. Metal frames $\frac{1}{8}$ inch wide soldered onto the ends of the sleeve held the glasses in place.

TABLE II. *Glass components of the 1936 and the superseded 1923 standards. (i) Jena GG9 yellow (melt F21725), (ii) Corning G30B signal yellow (melt 8–25–25), (iii) Corning G10M crystal clear, (iv) Corning 554CP amethyst, (v) Corning G34 (melt 7–1–30, T=5 percent at 556 mμ, 40 percent at 566 mμ), (vi) Corning G34 (melt 11–2–29, T=5 percent at 566 mμ, 40 percent at 577 mμ), (vii) Corning G24L (melt 5–8–34, T=5 percent at 580 mμ, 40 percent at 591 mμ); Y, R, B yellow, red, and blue Lovibond numerals, engraved by the manufacturer on the glasses used in set No. 100 of the 1923 standards, a, clear glass with wavy surface, b, wavy film of cellulose acetate.*

	1936 STANDARDS			1923 STANDARDS				
	THICKNESS OF COMPONENTS, MM			Y	R	B	CLEAR	NO. OF COMPONENTS
X	(i) 1.07	(ii) 0.78	(iii) 17.76	12	1.4	—	*a*	3
WW	1.07	1.17	17.60	20	2.1	—	*a*	3
WG	1.07	1.59	17.52	30	2.5	—	*a*	3
N	1.07	2.16	17.10	40	3.4	—	*a*	3
M	1.07	2.90	16.41	50	4.5	—	*a*	3
K	1.07	3.92	15.61	60	5.5	—	*a*	3
I	1.07	5.27	14.23	70	7.7	—	*a*	4
H	1.07	7.35	12.20	75	11.5	—	*a*	4
G	—	10.08	10.65	75	18.5	—	*a*	4
F	(v) 2.18	(iv) 2.19	16.06	100	35	—	*a*	5
E	(vi) 2.89	3.22	14.29	120	55	—	*a*+*b*	8
D	(vii) 1.60	5.27	13.70	150	83	2.0	*b*+*b*	8

* All grinding and polishing to specified thicknesses was done by the Frankford Arsenal of the War Dept.

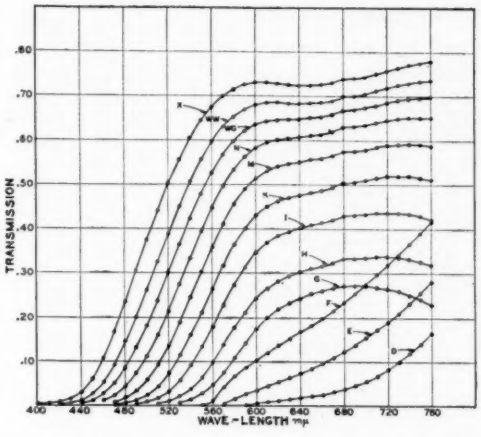


FIG. 3. Spectral transmission curves for the master set of the 1936 U.S. standards for rosin.

The spectral transmission data of Table I constitute a purely physical specification of the light transmitting properties of the master set of 1936 standards.

Psycho-physical specifications for the colors of these standards and also the superseded 1923 standards are given in Table III, based on the 1931 I.C.I. colorimetric coordinate system with its standard observer and standard illuminant *C*.[7] The trilinear coordinates x and y, together with the luminous transmissions T, suffice to specify completely the chromaticity and relative brightness of the colors by the tristimulus system. However, additional specifications are given in the table in terms of dominant wave-length and colorimetric purity, on the so-called homogeneous-heterogeneous system.[7] Specification in the latter form may be preferred by some because the three quantities Λ, p, and T give a numerical description of the three attributes, hue, saturation, and brightness of a color, and in fact all three of these attributes are taken into consideration in grading rosin.

IV. CHROMATICITY SPACING OF STANDARDS

A gradually increasing chromaticity difference between successive standards in the series from X to D was desired for the 1936 standards. This was accomplished by spacing the standards on the x trilinear-coordinate scale with a gradually

[7] D. B. Judd, J. Opt. Soc. Am. **23**, 359 (1933).

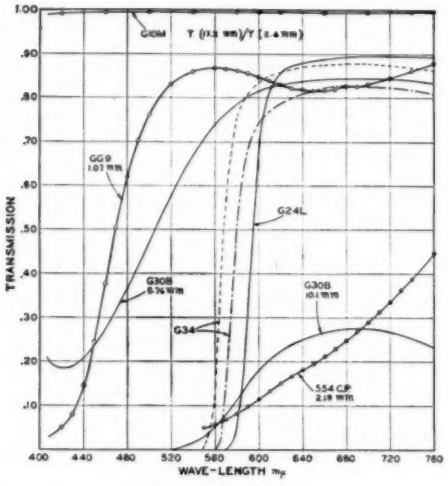


FIG. 4. Spectral transmission curves for glass components used in the 1936 standards.

increasing difference between x coordinates for successive standards.

This method of effecting a systematic spacing is based on the empirical relation, discovered by Judd,[8] that the chromaticity difference between two colors is proportional to the absolute value of the difference in their red or green trilinear coordinates, whichever difference is larger, in the O.S.A. colorimetric coordinate system. As Judd[9] has pointed out, this relation holds fairly well also for the (x,y)-mixture diagram of the I.C.I. colorimetric coordinate system.

Figure 5 illustrates the chromaticity spacing of the 1936 standards and also the 1923 standards in terms of differences between x coordinates for successive standards on the I.C.I. coordinate system, calculated from Table III. The spacing for the 1936 standards is much more regular than for the old standards. In setting up the new spacing the chromaticities of the WG and D standards were held the same as in the old standards (see Table III), and the colors of the remaining standards were shifted one way or the other on the x scale to achieve the more regular spacing.

A representation of the chromaticity spacing of the standards in closer agreement with chromaticity sensibility data for the eye is shown in curve III of Fig. 5, based on Judd's "uniform-chromaticity-scale" colorimetric coordinate system.[10] In this system the chromaticity difference between two colors represented by points on the Maxwell triangle is closely proportional to the length of the straight line joining the points. Values of D, calculated from Judd's Eq. (2), represent the distance between successive standards on this triangle. On the basis of these data, it may be stated that if, for example, under certain conditions of observation there are 17 just perceptibly different steps of chromaticity between the WW and WG standard colors, there are 32 such steps between the K and I colors and 65 between the F and E colors.

V. Chromaticity Tolerances for Duplicate Standards

One hundred and nine sets of glass combinations duplicating the master set No. 200 of the 1936 standards were made up to meet the expected requirements of the trade. The existence of color variations within certain of the glass melts listed in Table II made it necessary to establish chromaticity tolerances for duplicate standards and to examine, in pairs, all colored glasses ground and polished to thickness specifications. This was done by means of a wedge color comparator.

TABLE III. *Colorimetric specifications for the 1936 and the 1923 standards for rosin, based on the 1931 I.C.I. coordinate system, standard observer, equal-energy basic stimulus, and standard illuminant C; x and y trilinear coordinates, T luminous transmission; additional specifications, Λ dominant wave-length in mμ, and p colorimetric purity.*

	1936 Standards (Set No. 200)					1923 Standards (Set No. 100)				
	x	y	T	Λ	p	x	y	T^*	Λ	p
X	0.4339	0.4663	0.609	575.0	0.755	0.4303	0.4617	0.521	575.0	0.724
WW	.4579	.4732	.531	576.8	.851	.4585	.4683	.443	577.3	.838
WG	.4785	.4741	.466	578.5	.905	.4790	.4748	.391	578.5	.908
N	.5001	.4704	.396	580.5	.944	.4970	.4706	.328	580.3	.938
M	.5212	.4619	.322	582.8	.969	.5144	.4666	.281	581.9	.965
K	.5430	.4483	.245	585.5	.985	.5325	.4535	.228	584.4	.974
I	.5649	.4310	.178	588.7	.993	.5502	.4396	.157	586.9	.981
H	.5879	.4102	.1114	592.4	.997	.5792	.4147	.115	591.4	.989
G	.6116	.3874	.0723	596.8	.999	.6139	.3828	.077	597.7	.994
F	.6364	.3632	.0398	602.1	1.000	.6455	.3538	.033	604.4	.999
E	.6640	.3358	.0131	609.4	1.000	.6714	.3284	.0093	611.8	1.000
D	.6943	.3057	.0021	621.4	1.000	.6947	.3053	.0017	621.6	1.000

*Assuming $T=0.91$ for the wavy glass component, $T=0.85$ for a wavy film of cellulose acetate at all wave-lengths.

[8] D. B. Judd, J. Opt. Soc. Am. **22**, 72 (1932).
[9] See p. 363 of reference 7.
[10] D. B. Judd, J. Opt. Soc. Am. **25**, 24 (1935).

In the preliminary work of developing the new color standards the color comparator was equipped with wedges of rosin and it was found that the colors of rosin samples from X to G in grade could be closely matched by various thicknesses of Corning G30B signal yellow glass combined with a constant thickness of Jena GG9 yellow glass.

In its final form the wedge comparator comprised a Martens polarization photometer, a 1.07-mm piece of Jena GG9 (melt F21725) glass at the lower aperture, and two wedges of G30B (melt 8–25–25) glass movable before the lower aperture by means of a rack and pinion, with a mm scale for reading wedge settings. Each wedge was compensated for deviation by cementing it to an equal wedge of clear glass. The light source was a standardized 100-watt projection lamp operated near the voltage required to produce a color temperature of 2842°K, and with two 10-mm cells containing appropriate solutions[11] in the photometer eyepiece, the illuminant closely approximated I.C.I. standard illuminant *C*. With a sample before the upper aperture of the photometer the two halves of the photometric field were kept equalized in brightness by adjusting the polarization photometer while a chromaticity match was effected by adjusting the appropriate wedge.

Since the trilinear coordinates of t mm of Corning G30B (melt 8–25–25) glass combined with 1.07-mm Jena GG9 (melt F21725) glass were known (see Tables II and III), the trilinear coordinates of the wedge comparator became known.

The relations connecting wedge settings W_1 and W_2 for the two wedges, the thickness parameter t, trilinear coordinate x, and increments of these quantities are

$$t = -0.302W_1 + 9.55 = -1.038W_2 + 22.70, \quad (1)$$

$$\Delta t = -0.302\Delta W_1 = -1.038\Delta W_2, \quad (2)$$

$$x = 0.1643 \log_{10} t + 0.4458, \quad (3)$$

$$\Delta x = 0.0714\Delta t/t. \quad (4)$$

The linear relations (3) and (4) hold for $t = 1.2$ to $t = 13$ mm. For the few values of t outside this range, the relation between Δx and Δt was found by calculations based on spectral transmission measurements.

Relations (1) and (3) were useful in selecting the proper thickness of G30B glass to effect a systematic spacing of the new standards discussed in the previous section. The thicknesses of G30B glass listed in Table II are in terms of an adjusted scale expressed by Eq. (1), and actual thicknesses used in the various duplicate standards may differ slightly from these values.

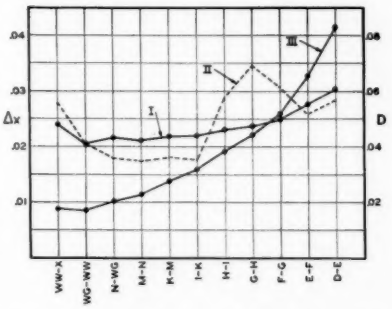


FIG. 5. Chromaticity spacing of standard colors in terms of differences Δx between x trilinear coordinates for successive standards on the I.C.I. coordinate system; I for 1936 master standards; II for 1923 master standards; III spacing for 1936 master standards in terms of distances between the standard colors on the Maxwell triangle of Judd's uniform-chromaticity coordinate system, values of D calculated from Judd's Eq. (2) (reference 10).

Relations (2) and (4) were useful in expressing deviations from the master standards for combinations examined for suitability as duplicate standards.

The first lot of combinations examined consisted of about 50 uncemented combinations of each of the 12 proposed types. The combination having the mean wedge setting of a group was selected as the master standard, and deviations from this standard were expressed in terms of Δt. Combinations in each group having largest values of Δt were rejected until the pale and red limits retained were judged by experienced graders to be within the tolerance for grading rosin.

In units of Δx the tolerance thus set up was ± 0.0020, that is all duplicate standards retained differed in x trilinear coordinate from the master standards by not more than ± 0.0020. (However, for 8 of the 12 grades, maximum deviations from the master standards did not

[11] See p. 360 of reference 7.

exceed ± 0.0014.) An equal tolerance for the y trilinear coordinate is implied. In terms of thicknesses of G30B glass, this tolerance is $\Delta t/t = \pm 2.8$ percent for standards WW to G and ± 3.7 percent for standard X.

Tests on the wedge comparator showed that no significant difference in wedge settings was obtained for addition of the clear glass component or for cementing the components of a combination with pale Canada balsam.

The second lot of combinations finished was examined by placing a known thickness of G30B glass plus the master standard at the upper photometer aperture and the duplicate combination (plus wedge) at the lower aperture, making 10 settings, then 10 more settings with the standard and duplicate interchanged. In this way values of Δt and Δx were evaluated even for the F, E, and D combinations.

From the large number of wedge settings made in the foregoing tests the probable error of a single wedge setting was evaluated in Δx units for different values of x. The averaged probable error of a single setting was found to be linear with x, expressed by the equation

$$\Delta x = -0.00045x + 0.00042.$$

This relation represents the sensibility, within a constant factor, of the writer's monocular vision with a 6° circular photometric field and other conditions of observation already described, to changes in the I.C.I. x coordinate along the locus of rosin standard colors from $x = 0.49$ to $x = 0.70$. The probable error of a single setting decreases from $\Delta x = 0.00019$ at $x = 0.494$ to $\Delta x = 0.00010$ at $x = 0.697$, and this variation verifies the expectation that Judd's empirical relation[8] between chromaticity sensibility and difference in trilinear coordinates applies only approximately for this case. This variation is in fair accord, however, with the spacing indicated by the "uniform-chromaticity-scale" triangle.[10]

V. Advantages of the New Standards

The improvements embodied in the 1936 U. S. rosin standards as compared with 1923 standards may be listed as follows:

(1) A closer spectral match with rosin.

(2) A higher brightness, more nearly equal to that of well-strained rosin now being produced.

(3) An improved regularity of spacing of the standard colors on a natural chromaticity scale.

(4) Smaller variations in color between duplicate sets of standards for most of the grades, and established chromaticity tolerances.

(5) Better optical surfaces, facilitating accurate colorimetric examination of assembled standards.

(6) A larger field of view, with a smaller dividing "line" between the standard and a juxtaposed rosin sample, through elimination of the metal frame in the ends of the protecting metal sleeve.

(7) A more solid construction, free from internal air spaces and easier to keep clean.

In conclusion the writer wishes to thank A. G. Sterling for mechanical work in the construction of apparatus; and the Corning Glass Works for courtesies extended early in this work.

Hue Sensibility to Dominant Wave-Length Change and the Relation Between Saturation and Colorimetric Purity

DOROTHY NICKERSON
Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C.
AND
WALTER C. GRANVILLE
Interchemical Corporation Research Laboratories, New York, New York
(Received January 26, 1940)

SENSIBILITY to wave-length change, and to purity differences has been studied by a number of investigators, the most widely quoted set of experimental data on wave-length probably being that of Jones,[1] and on purity differences that of Priest and Brickwedde.[2] There is a relation between such data and that of hue and saturation, but the relation is not always clearly understood. Nor has any considerable amount of data involving hue and saturation been previously published. That which is reported in this paper concerns the psychological concepts of hue and saturation, reported in relation to the psychophysical concepts of dominant wave-length and purity.

Judd,[3] in 1932, summed up the work to that date and described an empirical method for computing the approximate number of "least perceptible differences" between any two colors of the same brightness whose specifications were available. He showed that this empirical method was in substantial agreement with much of the experimental data obtained by others.

Troland,[4] in a discussion of the spectral chroma scale, indicates that "the manner in which pure hue depends upon wave-length cannot be ascertained by utilizing spectral or homogeneous stimuli alone." Further, he says, as he had previously in the 1922 report of the Colorimetry Committee,[5] "Although these investigators (König, Steindler, Jones, Laurens) have regarded their results as establishing a scale of pure hue, the scale in question must, in strictness, be called the *spectral chroma scale.*" The italics are Troland's. He pointed out that the colors actually presented in the spectrum vary simultaneously in hue and saturation as a function of wave-length. In the colorimetry report Troland states that "no determinations have yet been made of the number of hue steps in cycles of color with uniform saturation." Certain preliminary comparative saturations were experimentally determined by the flicker method and reported by Troland in support of his statement that differences in saturation of spectral colors are of first-order importance.

In 1931 Purdy discussed certain phases of this subject in reporting studies made in Troland's laboratory.[6] Since that time Sinden has discussed the matter further.[7] In Germany, Klughardt,[8] Richter[9,10] and Kohlrausch and Meerendonk[11] have been working on this subject, and more recently there has been a report by Rosemann.[12]

Judd reports that the outstanding limitation of data to be found in the literature is the almost complete lack of data pertaining either to large color differences, or to purple colors.

[1] L. A. Jones, "The Fundamental Scale of Pure Hue and Retinal Sensibility to Hue Differences," J. Opt. Soc. Am. **1**, 63–77 (1917).
[2] I. G. Priest and F. L. Brickwedde, "Minimum Perceptible Colorimetric Purity as a Function of Dominant Wave-length," J. Opt. Soc. Am. **28**, 133–139 (1938).
[3] Deane B. Judd, "Chromaticity Sensibility to Stimulus Differences," J. Opt. Soc. Am. **22**, 72–108 (1932).
[4] L. T. Troland, *Psycho-Physiology* (Van Nostrand, 1930), Vol. II, pp. 142–147.
[5] L. T. Troland, *et al.*, "Report of the Colorimetry Committee of the Optical Society of America, 1920–21," J. Opt. Soc. Am. and Rev. Sci. Inst. **6**, 527–596 (1922).
[6] D. McL. Purdy, "On the Saturations and Chromatic Thresholds of the Spectral Colours," Brit. J. Psych. **21**, 283–313 (1931).
[7] R. H. Sinden, "A Further Search for the Ideal Color System (II)," J. Opt. Soc. Am. **28**, 339–347 (1938).
[8] A. Klughardt, "Untersuchungen zur Farbenlehre III," Zeits. f. tech. Physik **10**, 101–103 (1929).
[9] M. Richter, "Methodik und Apparatur für psychophysische Untersuchungen zur höheren Farbenmetrik," Zeits. Sinnesphysiologie **66**, 67–102 (1935); "Die Transformation der trichromatischen Koordinaten einer Farbe auf Ostwald-Koeffizienten," Zeits. f. tech. Physik **12**, 582–587 (1931).
[10] A. Klughardt and M. Richter, "Experimentelle Bestimmung einer Farbreihe empfindungsgemäss gleicher Sättigung," Zeits. Sinnesphysiologie **66**, 103–136 (1935).
[11] A. Kohlrausch and P. v. Meerendonk, "Ueber den Geltungsbereich spektraler Farbengleichungen," Zeits. Sinnesphysiologie **66**, 45–65 (1935).
[12] J. Rosemann, "Series of Colors of Equal Subjective Saturation," Zeits. f. tech. Physik **20**, 198–203 (1939).

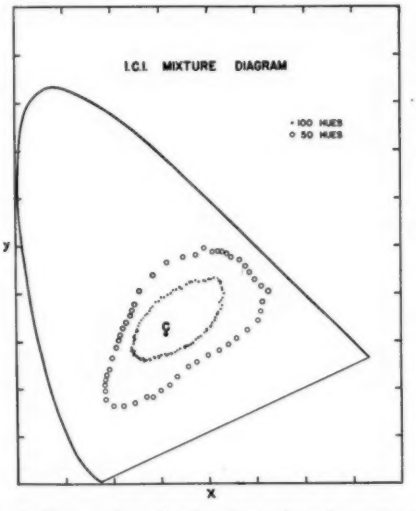


FIG. 1. Two series of color data plotted on the 1931 I.C.I. mixture diagram: (1) a series of 100 Munsell hues at constant lightness and saturation (5/5's), (2) 50 hues, with lightness and saturation varied to give a series of naximum saturation (maximum for permanent and available pigments at the time the series was painted).

The following data are reported in order to supply certain information reported lacking by Troland and Judd: (a) they refer to hue change only rather than simultaneous variation of both hue and saturation, (b) the intervals are larger than "least perceptible" and are different in size for the two sets of data employed, (c) they include the purples, and (d) they include data on variation of colorimetric purity for constant saturation throughout a closely stepped hue scale. They are derived from spectral reflectance measurements of two experimental sets of Munsell papers. One set of papers consists of 100 hues at constant value and chroma (5/5), and the other set consists of 50 hues at maximum saturation for pigment colors. No papers can be produced to represent perfect equality in hue difference between pairs of adjacent colors, but these two sets of papers provide an adequate approximation to equality. A limited stock is available from the Munsell laboratory for study or visual observation by any student who may doubt that they adequately represent equally stepped hue scales.

The spectral-reflectance curves were made on a General Electric model of the Hardy recording spectrophotometer using a freshly prepared layer of magnesium oxide, 0.06 inch thick, as the standard of reflectance. The instrument allows the sample and standard to be irradiated normally by a 10-mμ wave-length band and viewed diffusely by an integrating sphere. All samples were backed by black velvet cloth having a reflectance of approximately 0.5 percent throughout the spectrum. I.C.I. tristimulus values were calculated by the Hardy 30-selected ordinate method[13] for Illuminant "C." Fig. 1 shows the

TABLE I. *Dominant wave-length and colorimetric purity for a series of 100 Munsell hues at constant lightness and saturation.*

MUNSELL NOTATION*	λ	dλ	P_c (%)	MUNSELL NOTATION	λ	dλ	P_c (%)
1R 5/5	492.5c†	0.5	−27.9	1BG 5/5	497.8	2.0	24.1
2	633.0	—	16.8	2	495.9	1.9	24.2
3	610.8	22.2	23.2	3	494.4	1.5	23.2
4	607.5	3.3	25.8	4	493.0	1.4	23.8
5	603.8	3.7	27.9	5	492.2	0.8	23.0
6	600.7	3.1	32.4	6	491.9	0.3	23.2
7	599.5	1.2	33.4	7	490.3	1.6	23.3
8	597.0	2.5	36.5	8	489.8	0.5	23.4
9	595.0	2.0	40.2	9	489.0	0.8	22.0
10	592.9	2.1	43.2	10	488.2	0.8	22.0
1YR	591.1	1.8	46.6	1B	487.1	1.1	21.4
2	589.7	1.4	49.0	2	485.8	1.3	21.7
3	588.6	1.1	52.5	3	485.2	0.6	21.0
4	587.0	1.6	56.2	4	484.7	0.5	20.9
5	585.2	1.8	57.0	5	484.1	0.6	18.4
6	584.7	0.5	59.3	6	483.3	0.8	18.4
7	584.0	0.7	61.6	7	482.8	0.5	17.5
8	582.6	1.4	64.9	8	482.4	0.4	17.0
9	581.4	1.2	65.8	9	481.7	0.7	15.4
10	580.2	1.2	67.3	10	480.8	0.9	14.1
1Y	579.1	1.1	69.5	1PB	480.1	0.7	13.2
2	578.5	0.6	70.3	2	479.1	1.0	11.8
3	577.7	0.8	70.5	3	478.1	1.0	10.7
4	576.7	1.0	71.5	4	476.5	1.6	9.4
5	575.6	1.1	70.1	5	475.9	0.6	8.1
6	575.2	0.4	67.8	6	474.8	1.1	7.4
7	574.5	0.7	66.9	7	472.3	2.5	6.1
8	573.9	0.6	64.4	8	469.8	2.5	4.6
9	573.0	0.9	64.2	9	465.0	4.8	2.9
10	571.8	1.2	61.5	10	459.0	6.0	2.2
1GY	570.0	1.8	60.9	1P	445.0	14.0	0.8
2	569.0	1.0	58.6	2	566.9c		−42.2
3	567.8	1.2	57.6	3	564.0c	2.9	−37.5
4	566.4	1.4	54.3	4	562.7c	1.3	−39.2
5	564.6	1.8	49.2	5	559.0c	3.7	−33.1
6	563.4	1.2	49.5	6	552.0c	7.0	−29.3
7	561.4	2.0	46.9	7	547.7c	4.3	−30.4
8	558.9	2.5	44.7	8	543.2c	4.5	−28.1
9	556.8	2.1	43.0	9	535.0c	8.2	−24.6
10	554.2	2.6	39.0	10	529.2c	5.8	−24.4
1G	549.7	4.5	36.0	1RP	517.3c	11.9	−22.5
2	545.0	4.7	34.6	2	509.8c	7.5	−21.4
3	539.1	5.9	31.2	3	504.9c	4.9	−21.6
4	530.5	8.6	28.7	4	499.0c	5.9	−23.7
5	520.0	10.5	24.6	5	499.7c	0.7	−23.9
6	514.4	5.6	24.0	6	498.1c	1.6	−25.0
7	509.6	4.8	22.8	7	496.9c	1.2	−26.5
8	505.5	4.1	22.8	8	496.0c	0.9	−26.6
9	502.3	3.2	23.3	9	494.8c	1.2	−26.9
10	499.8	2.5	23.2	10	493.0c	1.8	−27.2

* The numbers of these papers are 101–200, beginning with 5R 5/5 at 101.

† Colors are complementary in dominant wave-length only for a given illuminant. Munsell colors are not painted under Illuminant "C." For the last 10–15 years they have checked under Macbeth light at a color temperature approximating 5700–5800°K. Before that time they were made in daylight, the best that could be obtained in any given location.

[13] A. C. Hardy, *Handbook of Colorimetry* (Technology Press, 1936).

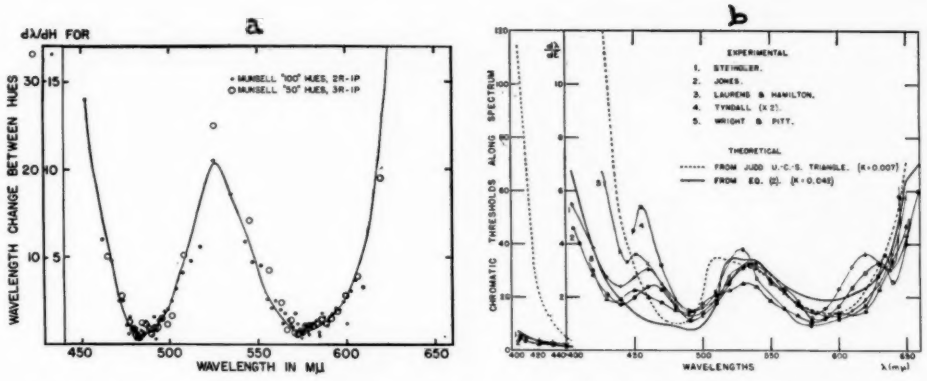


FIG. 2. Wave-length difference: (a) for constant Munsell hue differences; (b) for constant chromaticity differences previously published. (Reference 14.)

two series plotted on an I.C.I. mixture diagram.

Dominant wave-length and colorimetric purity, based on 100 hues in the complete circuit, with lightness and saturation constant, are given in Table I, together with the dominant wave-length differences corresponding to each Munsell hue step. Similar data based on 50 hues in the complete circuit, with lightness and saturation varying to give a series of maximum saturations, are given in Table II.

Figure 2 is a comparison chart of dominant wave-length differences, (a) corresponding to constant hue difference and (b) corresponding to constant chromaticity difference. The 100 hues at constant lightness and saturation give as expected, dominant wave-length difference numbers about twice the size of those for the 50-hue series [note Fig. 2(a)]. It is evident that the shape of the curve [Fig. 2(a)] of dominant wave-length difference for constant difference in Munsell hue is essentially the same regardless of whether lightness and saturation is kept constant for single steps of Munsell hue (as in the 5/5 series), or is varied throughout a considerable range (as in the second series) for hue intervals of two Munsell hue steps each. Comparison of Fig. 2(a) with Fig. 2(b) shows that the hue scale bears only a superficial resemblance to the spectral chromaticity scale. The maxima, in both sets of data, come at the ends of the spectrum, and near 525 mμ, the minima near 485 and 575 mμ. But the ratio of maxima to minima for the central peak is nearly 20 : 1 for the hue scale, and only about 4 : 1 for the spectral chromaticity scale.

Figure 3 shows the variation of purity with dominant wave-length for saturation constant, (3a) at moderate saturation (Munsell/5), and (3b) for saturation very small (at threshold values).[14] It seems obvious that the relation is considerably more than a casual one.

The above material, the authors believe, presents for the first time data on any consider-

TABLE II. *Dominant wave-length and colorimetric purity for a series of 50 Munsell hues with lightness and saturation varying to give maximum saturation for pigment colors.*

MUNSELL HUE	λ	dλ	P_c (%)	MUNSELL HUE	λ	dλ	P_c (%)
1R	493.0c	1.5	−58.7	1BG	497.4	2.3	33.0
3	629.0		35.5	3	494.4	3.0	33.2
5	610.0	19.0	49.1	5	492.4	2.0	34.3
7	602.2	7.8	62.5	7	490.5	1.9	34.4
9	596.6	5.6	70.3	9	489.3	1.2	34.5
1YR	592.8	3.8	76.9	1B	487.6	1.7	34.6
3	589.8	3.0	85.3	3	485.3	2.3	35.4
5	587.4	2.4	84.9	5	482.8	2.5	35.4
7	584.5	2.9	85.2	7	482.0	0.8	36.8
9	582.0	2.5	87.1	9	481.2	0.8	37.7
1Y	579.8	2.2	88.1	1PB	480.0	1.2	36.7
3	577.6	2.2	88.4	3	478.3	1.7	34.7
5	575.5	2.1	86.9	5	475.7	2.6	31.7
7	574.0	1.5	86.9	7	470.1	5.6	20.6
9	572.7	1.3	86.0	9	460.0	10.1	9.6
1GY	571.5	1.2	84.5	1P	420.0	40.0	1.4
3	570.1	1.4	82.0	3	563.4c		−152.0
5	567.3	2.8	80.8	5	559.6c	3.8	−143.0
7	565.6	1.7	75.3	7	555.5c	4.1	−117.1
9	560.8	4.8	68.8	9	547.2c	8.3	−93.1
1G	552.3	8.5	60.5	1RP	532.7c	14.5	−65.1
3	538.2	14.1	47.8	3	510.0c	22.7	−48.0
5	513.2	25.0	36.8	5	502.2c	7.8	−49.3
7	503.0	10.2	33.8	7	497.1c	5.1	−52.5
9	499.7	3.3	33.4	9	494.5c	2.6	−56.0

[14] All (b) charts are taken from (7) and are used by permission of both Sinden and Judd.

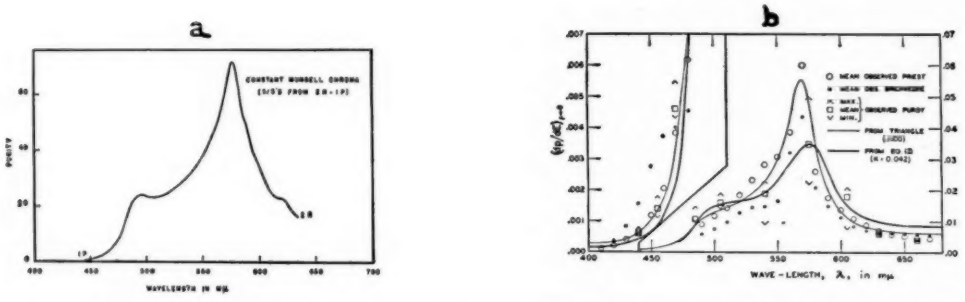


FIG. 3. Colorimetric purity as a function of dominant wave-length: (a) for saturation held constant at a moderate level (Munsell /5), and (b) for saturation held constant at the threshold (first steps from sunlight toward spectrum colors).

able series of surface colors. It is their belief also that such data must be taken into consideration in the perfection of uniform chromaticity-scales, or conversion formulas for uniform chromaticity-scales to be used with I.C.I. data.

When adequate uniform-chromaticity-scale data are available, it should be possible, with I.C.I. diagrams for a selected series of lightness levels, each with lines of uniform hue and saturation, to use directly the I.C.I. values, without having to forego the advantages of a sensation scale.

The Fluorescent Mercury-Vapor Lamp as a Light Source for a Single-Point Check on Optical Pyrometers*

C. F. Lucks and H. W. Russell
Battelle Memorial Institute, Columbus, Ohio
(Received February 3, 1940)

IT is often desirable to have a dependable light source for making a quick and convenient single-point check on an optical pyrometer. The 15-watt pink fluorescent mercury-vapor lamp has been studied and the results show that its characteristics make it suitable for such use.

Optical pyrometers are usually calibrated by the use of a wide ribbon filament tungsten lamp. A set-up of this type has been described by Baeyertz and Perkins.[1] Because of initial and upkeep costs, equipment for calibrating optical pyrometers has been limited largely to specialized laboratories, users of large numbers of optical pyrometers and to centralized laboratories such as are maintained by associations or groups of small industrial plants. As a result many users of optical pyrometers, especially those in the small industrial plants, do not have at hand a suitable light source for calibrating their instruments.

Aside from the facilities for calibration, a large number of industrial plants and other users of optical pyrometers do not have a suitable light source for making a check on their optical pyrometers. Consequently, in a number of instances instruments have been in gross error without the user having the slightest knowledge of it. A simple check would serve, in most cases, to eliminate such errors.

A method utilizing the freezing points of killed steel ingots for checking the standardization of optical pyrometers has been described by Cook.[2]

The less expensive and more "portable" set-up for making checks rather than a calibration usually has as the light source a calibrated ordinary incandescent light bulb or a projection lamp with suitable screens. The above lamps have certain disadvantages, such as a too small area of uniform brightness, need of a rather accurate means for indicating and controlling lamp output and the dissipation of an inconvenient quantity of heat. The 15-watt pink fluorescent mercury-vapor lamp recently placed on the market is free from these drawbacks.

Fifteen pink 15-watt fluorescent mercury-vapor lamps 18 inches long and 1 inch in diameter were used in the study of the fluorescent lamp as a light source for a single-point check on optical pyrometers. The lamps designated as 18-inch T-8 pink fluorescent mazda lamps were obtained from the Fluorescent Lamp Works of the General Electric Company at Cleveland, Ohio. The lamps were selected after a seasoning period of 100 hours as having approximately the same voltage drop and the same brightness as given by eye observation. A circle approximately $\frac{3}{8}$ inch in diameter was drawn with India ink at the central region of each lamp. Observations were confined to the area within the circle. The thermal switch type auxiliary was used with lamps in the present work. No doubt lamps of other manufacture seasoned and selected in the same manner would yield results similar to those obtained with the present lamps.

Two commercial optical pyrometers of different type and manufacture were used for making observations on the lamps. One pyrometer was of the disappearing filament type manufactured by the Leeds and Northrup Company. This instrument was of the model previous to the potentiometer direct-reading model recently

Table I. *Initial apparent brightness temperature for the 15 lamps observed. Line voltage, 115; room temperature, 86° F.*

Lamp No.	Temp. °F	Lamp No.	Temp. °F
1	2028	9	2042
2	2028	10	2038
3	2023	11	2028
4	2038	12	2038
5	2033	13	2019
6	2035	14	2040
7	2020	15	2025
8	2015		

* Paper No. 48 presented November 2, 1939, at the American Institute of Physics Temperature Symposium, New York, New York.

[1] M. Baeyertz and J. F. Perkins, Metal Progress **36**, 145 (1939).

[2] E. Cook, Trans. Am. Soc. for Metals **24**, 649 (1936).

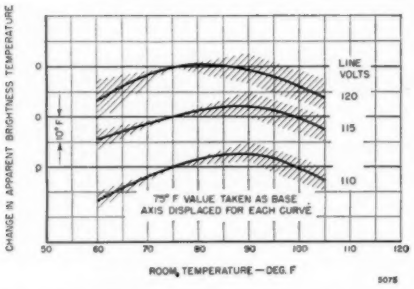


FIG. 1. The effect of room temperature for three line voltages on the apparent brightness temperature of five pink fluorescent mercury-vapor lamps.

placed on the market by that company. The other instrument was of the wedge type manufactured by the Pyrometer Instrument Company. Both pyrometers had red filters of approximately 0.65μ wave-lengths. The apparent brightness temperatures were found to be the same, within the limit of experimental error, for both pyrometers.

The initial apparent brightness temperatures of the fifteen lamps observed are given in Table I. The value given in the table is the average obtained from observations with both pyrometers. The two values were identical for a number of the lamps and the maximum difference for any pair was 10°F. Lamps 8 and 9 showed the low of 2015°F and the high of 2042°F, respectively, in initial brightness temperature. The 27°F difference between these two values is real. The existence of a difference was easily confirmed by matching the pyrometer on one lamp, then sighting the pyrometer, so adjusted, immediately on the other lamp. A very definite lack of match was observed. The variation observed in the initial brightness temperatures of the fifteen lamps indicates that unless the lamps are critically selected after a seasoning period of 100 hours each lamp should be individually calibrated for apparent brightness temperature.

Data in the literature by Inman,[3] Marden *et al.*,[4] Thayer and Barnes,[5] and Inman and Thayer[6] relative to the general characteristics of the fluorescent mercury-vapor lamp indicate that ambient temperature, line voltage, lamp current and lamp life are the principal factors to be considered in the use of the lamp for making checks on optical pyrometers.

Five of the fluorescent mercury-vapor lamps were placed in a controlled temperature cabinet. Provision was made so that there was no intervening material such as glass between the lamp being observed and the optical pyrometer.

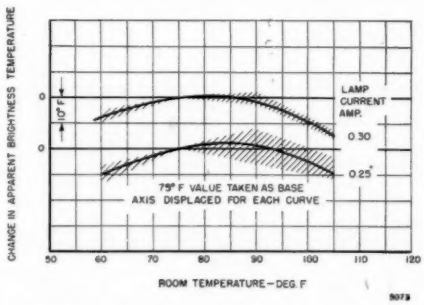


FIG. 2. The effect of room temperature for two lamp currents on the apparent brightness temperature of five pink fluorescent mercury-vapor lamps.

Observations with the optical pyrometer were made on the lamps at various air temperatures and line voltages. The air temperature will hereafter be referred to as room temperature. Lamp current and lamp voltage were also observed.

Figure 1 shows the effect of variation in room temperature for three line voltages on the apparent brightness temperature of the lamps. In this and following figures the shaded area represents the spread in observed data and the solid line the average curve. Fig. 2 shows the effect of variation in room temperature for two

TABLE II. *Lamp wall temperatures for one pink fluorescent lamp at observed line voltages and room temperatures.*

Room Temp. °F	Lamp Wall Temperature, °F			
	110 Volts	115 Volts	120 Volts	125 Volts
60	88.2	90.5	94.7	—
75	102.1	104.3	108.2	110.2
90	113.7	118.6	121.3	—
105	129.4	131.3	134.8	136.3

Min. lamp wall Temp., 88.2°F = (31.2°C).
Max. lamp wall Temp., 136.3°F = (58.0°C).

[3] G. E. Inman, Trans. I. E. S. **34**, 65 (1939).
[4] J. W. Marden, N. C. Beese, and G. Meister, Trans. I. E. S. **34**, 55 (1939).
[5] R. N. Thayer and B. T. Barnes, J. Opt. Soc. Am. **29**, 131 (1939).
[6] G. E. Inman and R. N. Thayer, Trans. Am. Inst. Elect. Eng. **57**, 723 (1939).

lamp currents on the apparent brightness temperature of the lamps. In Table II are given the lamp wall temperatures at various room temperatures for one of the lamps. The variation in light intensity with lamp wall temperature has been reported for fluorescent lamps by Marden, Beese, and Meister[4] and is reproduced in Fig. 3. It will be noted from Table II that the range of lamp wall temperature (31°C to 58°C) resulting from room temperatures of 60°F to 105°F comes in the region of maximum light intensity of Fig. 3. Since the optical pyrometer measures monochromatic intensities the data of this figure are not directly applicable but serve to indicate that the general shape of the curves of Figs. 1 and 2 is as might be expected.

The effect of variation in line voltage and lamp current for four room temperatures on the apparent brightness temperature of the lamps is shown in Figs. 4 and 5, respectively. From Fig. 4 it will be observed that a change of approximately 15°F in apparent brightness temperature results from a change of 5 volts in

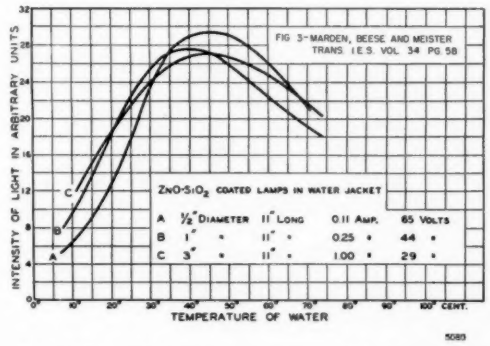


FIG. 3-MARDEN, BEESE AND MEISTER
TRANS. I.E.S. VOL. 34 PG. 58
INTENSITY OF LIGHT IN ARBITRARY UNITS
ZnO·SiO2 COATED LAMPS IN WATER JACKET
A ½" DIAMETER 11" LONG 0.11 AMP. 65 VOLTS
B 1" " 11" " 0.25 " 44 "
C 3" " 11" " 1.00 " 29 "
TEMPERATURE OF WATER
5089

FIG. 3. The effect of temperature on light from fluorescent lamps immersed in water. (Marden, Beese, and Meister, reference 4.)

line voltage. Fig. 5 shows that approximately the same change in apparent brightness temperature results from a change of 0.05 ampere in lamp current. These data indicate that meters of only moderate accuracy are required for indicating adjustments in line voltage and lamp current to obtain with reasonable accuracy a certain apparent brightness temperature at any given room temperature. Since the line voltage measurement includes the voltage drop across

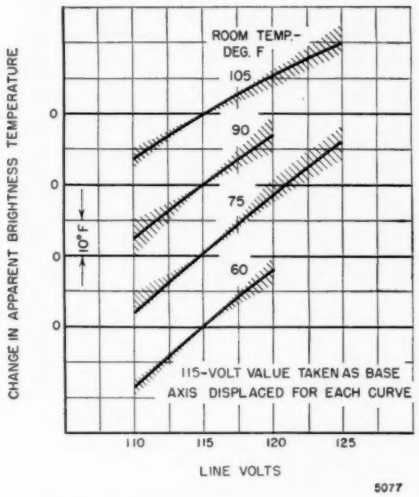


FIG. 4. The effect of line voltage for four room temperatures on the apparent brightness temperature of five pink fluorescent mercury-vapor lamps.

the auxiliary reactance, lamp current is preferred to line voltage for use in adjusting the lamp to a given apparent brightness temperature.

Figure 6 is a reproduction of two curves from a figure given by Inman[3] showing the characteristic changes for the fluorescent lamp with changes in line voltage. The shaded area of this figure shows the spread in the data obtained in the present investigation. The figure is presented to show that the general characteristics of the lamps used in the present work are in agreement with published data.

Ten of the pink 15-watt fluorescent mercury-vapor lamps were observed for the effect of lamp life on apparent brightness temperature. As stated previously, all lamps had been given a seasoning period of 100 hours, hence the times and cycles given in life tests are in addition to this period. During the life tests the lamps were operated at 115 volts line voltage and corrections for variation in room temperature were made according to the 115-volt curve of Fig. 1. The largest correction was 6°F and for practical purposes it can be said that the tests were made under constant conditions.

Five of the life test lamps were operated continuously for 180 hours. Observations were made at 10-hour intervals. Table III gives the

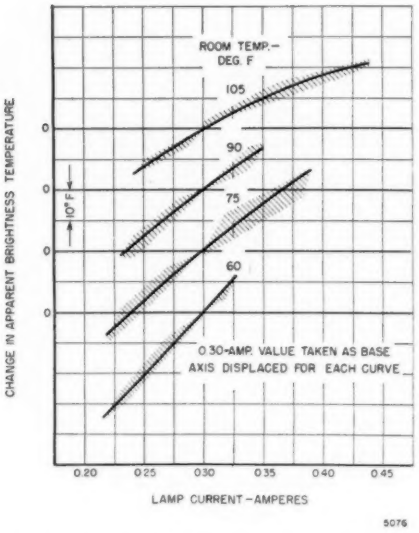


FIG. 5. The effect of lamp current for four room temperatures on the apparent brightness temperature of five pink fluorescent mercury-vapor lamps.

initial, maximum, minimum, and final apparent brightness temperatures observed during the tests. The greatest difference between maximum and minimum observed apparent brightness temperature for the lamps was 21°F (lamp number 13). Since the initial and final temperatures for most of the lamps were between the maximum and minimum values observed it is evident that, for check purposes at least, continuous operation of the lamps for 180 hours after a seasoning period of 100 hours had no effect on the apparent brightness temperature of the lamps. The differences in observed apparent brightness temperatures for a given lamp are believed due largely to the personal factor always present in optical pyrometer measurements.

The other five life test lamps were operated intermittently. A cycle of 10 minutes on and 10 minutes off was used. Table IV gives the initial, maximum, minimum, and final observed apparent brightness temperatures for the lamps during a 540-cycle test. Observations were made every 30 cycles. The greatest variation in apparent brightness temperature for any one lamp was 22°F noted for lamp number 6. The data are quite similar to those obtained for continuous operation of the lamps and show that 540 intermittent operations of the lamps for 10-minute periods had practically no effect on the apparent brightness temperatures of the lamps. Although the life test data show that up to at least 180 hours continuous operation or 540 ten-minute intermittent operations lamp life has no effect on the apparent brightness temperature of the fluorescent mercury-vapor lamp a calibration of the lamp at intervals is suggested.

Another factor influencing the apparent brightness temperature of the fluorescent mercury-vapor lamp is the deposition of mercury at the spot being sighted on. When this occurs the mercury can be vaporized from the spot by temporarily placing thermal insulation on the tube at that location. In the observed cases this treatment has been satisfactory.

It should be observed that the fluorescent mercury-vapor lamp offers only a single-point check on the optical pyrometer and hence does not check the instrument over its entire range. In making single-point checks such things as an indicating instrument lacking uniformity in calibration, the possibility of there being spots

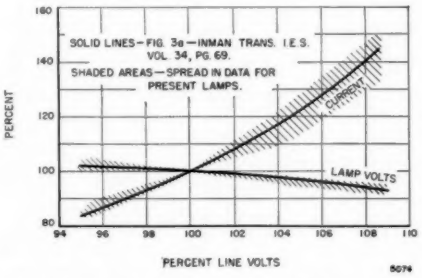


FIG. 6. Changes in lamp current and lamp voltage with variation in line voltage for fluorescent mercury-vapor lamps. (115-volt value at each of four room temperatures taken as base.)

on the wedge and the like, should be taken into consideration for each optical pyrometer so checked. Suitable grey filters or sector disks could be used with the lamp to obtain a range of apparent brightness temperatures, a lower apparent brightness temperature, or, in the case of a double range pyrometer, to give an apparent brightness temperature on the lower range such that the range filters would be the only difference between checking and use.

A set-up using the fluorescent mercury-vapor lamp for making single-point checks on optical pyrometers is shown in Fig. 7. The equipment consists of a 15-watt pink fluorescent mercury-vapor lamp, a variable autotransformer, an indicating instrument, and a thermometer for measuring room temperature. The latter is not shown in the figure. The indicating instrument in the figure is a voltmeter connected directly across the output of the autotransformer. It is preferable, as stated, to use a milliammeter measuring lamp current, and adjust current rather than voltage.

An application of the fluorescent mercury-vapor lamp of no less importance than its use in making single-point checks is in the intercomparison of two or more optical pyrometers. The observed constancy of the lamp makes it valuable for this purpose. Two optical pyrometers which check against a fluorescent mercury-vapor lamp should generally also check at other observed temperatures in subsequent use.

FIG. 7. Set-up for making single-point checks on optical pyrometers.

TABLE III. *Apparent brightness temperatures for 180 hours continuous operation.**

LAMP NO.	TEMPERATURE, °F			
	INITIAL	MAXIMUM	MINIMUM	FINAL
11	2028	2034	2016	2020
12	2038	2039	2022	2025
13	2019	2026	2005	2013
14	2040	2039	2026	2027
15	2025	2030	2016	2022

* Lamps seasoned 100 hours before test.

TABLE IV. *Apparent brightness temperatures for intermittent operation. 540 cycles, 10 minutes on, 10 minutes off.**

LAMP NO.	TEMPERATURE, °F			
	INITIAL	MAXIMUM	MINIMUM	FINAL
6	2035	2041	2019	2019
7	2020	2030	2013	2019
8	2015	2030	2015	2022
9	2042	2051	2034	2035
10	2038	2048	2031	2032

* Lamps seasoned 100 hours before test.

The simplicity, low cost, constancy and ease of control of the 15-watt pink fluorescent mercury-vapor lamp make it a suitable light source for making single-point checks and intercomparisons of optical pyrometers. The accuracy obtainable with the fluorescent lamp is as good as with previously mentioned lamps and greater than claimed for the method described by Cook.[2] These factors suggest that optical pyrometers could be checked for gross errors at the place of use in all industrial plants. Thus the open hearth foreman would have a means of checking and intercomparing his optical pyrometers for gross error at any time he saw fit.

Visibility Through Haze and Smoke, and a Visibility Meter

G. D. SHALLENBERGER AND E. M. LITTLE
*Physics Department, State University of Montana, Missoula, Montana**

(Received January 29, 1940)

Air clarity (c) is defined as the distance from an observer to a black ridge, or dark building, or some similar object when it is just barely visible against the horizon sky. The expression is derived for visual range (v) in miles of a small smoke, such as a Forest Service lookout would be expected to detect. Visual range depends upon direction with respect to the sun, clarity, height of smoke layer, binocular power, and Fechner's constant for the observer. The expression cannot be solved explicitly for v but families of curves are plotted. One interesting result is that under certain conditions, adding smoke to all the air *increases* the visual range of a small smoke. A visibility meter was constructed to determine clarity (general visibility). The form of meter finally adopted is to be slipped over one objective of a binocular. It consists essentially of a small-angle prism (0.5 diopter) that is moved past a small aperture before the objective. When covering part of the aperture there are two images in the field of view, the added one being due to the prism. As the prism covers more and more of the aperture, the original image grows weaker and the new one grows stronger. When the original image becomes so weak that the boundary line between the object (e.g., ridge or dark building) and the horizon haze just disappears, the distance the observer would have to be from the object for it to be just barely visible may be calculated from the position of the prism and the actual distance of the object. This is c. Curves are drawn to save calculations by the operator. The meter is adapted for use at Forest Service fire lookouts, airports, etc.

INTRODUCTION AND LITERATURE

IN the warfare waged by the U. S. Forest Service against forest fires, visibility is a factor of considerable concern. The clarity of the atmosphere should be measured more accurately than can be estimated by lookouts. Thus there is need of a visibility meter to measure the visual range of objects (greatest distance visible). Furthermore, knowledge of the variation of visual range of objects with azimuth, direction of sun, smokiness, etc. is desirable so that the useful "seen area" around a lookout tower can be determined for various conditions. It was with this in mind that the present investigation of the visibility of smoke columns was carried out, being financed by the Northern Rocky Mountain Forest and Range Experiment Station.

The literature treating the fundamental aspects of this subject is meager. Jones[1] and Bennett[2] have published studies on the visibility of objects as influenced principally by moisture haze. While both have made use of the Weber-Fechner stimulus-sensation law, neither has developed a comprehensive theory. Jones mentions haze light and haze absorption but does not give an expression relating their variation to distance. Bennett considers haze absorption, but neglects haze light. Since the readings of Bennett's visibility meter depend as much upon brightness of illumination as upon contrast, it occurs to one that it would not give consistent results when used under conditions of varying brightness. It is shown in the present study that in general the visibility of objects is the *same* on sunny as on cloudy days. Jones' visibility meter is sound in principle but rather complicated. His use of an artificial source—a filament lamp—requires two readings to compare sky light and haze light with the lamp light, whereas with an instrument without an artificial source the sky light and haze light may be compared at one reading. The meter described by Byram[3] is based upon sound theory, but in use it encounters two objections:

(1) There must be on the observer's sky line at least one ridge at "the distance of photometric balance."

(2) The blue filter gives visibility for blue light. This is not proportional to visibility in light of other spectral quality, including white light. The quality of outdoor light varies with the type and the amount of haze. Middleton[4] has pub-

* In collaboration with the Northern Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Missoula, Montana.

[1] L. A. Jones, Jr., Phil. Mag. **39**, 96 (1920).

[2] M. G. Bennett, Q. J. R. Met. Soc. 56 (1930), No. 233.

[3] G. M. Byram, J. Opt. Soc. Am. **25**, 388–392 (1935).

[4] Middleton, *Visibility in Meteorology* (University of Toronto Press, 1935).

lished an excellent book on visibility. His "artificial star" photometer described in his book on pp. 62–64 can be used either by day or night for visibility measurement and the results do not depend on the sensitivity of the observer's eye. It is, however, somewhat expensive and it cannot be used at casual stations, but we consider it the best all-round type of meter if expense is not an item. Our meter is a low-cost instrument for daytime use.

Air Clarity

Most atmospheric "apparent absorption" is due to the scattering of light by air molecules and by suspended particles, such as moisture or smoke particles. Rayleigh showed that, for particles small compared with the wave-length of light the intensity of the scattered light is proportional to $1+\cos^2\theta$, where θ is the angle between the scattered ray and the incident ray. This variation of intensity with θ is shown by the sinusoidal curve—dotted—in Fig. 1. For particles of a uniform size with a diameter comparable with the wave-length of light, a definite diffraction pattern with decreasing maxima and minima is formed. For a group of particles of varying size the maxima and the minima are absent. This case is shown by the exponential-looking curves of Fig. 1.

Consider a slab of hazy air with a thickness of dx and of unit cross section. Let a beam of light of an intensity i be incident upon it. The intensity of the beam will be diminished by the amount $aidx$ (a is the apparent absorption coefficient) due to scattering away from the beam; it will be increased by the amount sdx (s is the scattering coefficient and is independent of x) due to scattering toward the beam from other directions. The net gain is

$$di=sdx-aidx.$$

By integration

$$i=(1-e^{-ax})s/a+i_0e^{-ax}, \qquad (1)$$

where i_0 is the light intensity in the beam at $x=0$—at the object viewed.

The Weber-Fechner stimulus-sensation constant was found to be 0.032 for the fields and boundaries viewed in this investigation. Nutting,[5] with fields with sharper boundaries produced under precision laboratory conditions for monochromatic light, found a value of 0.016 for this constant. This constant is defined by the equation,

$$(i_1-i_2)/i_1=0.032, \qquad (2)$$

where i_1 and i_2 are the intensities of two juxtaposed fields that can just be distinguished.

As one retreats from a nearby mountain side, haze light between him and the mountain

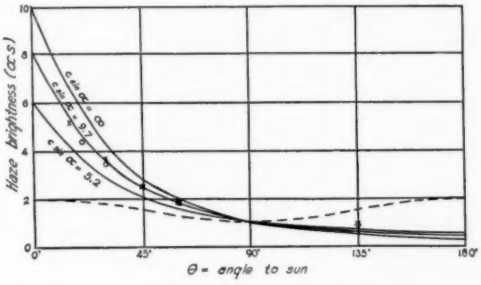


Fig. 1. Haze brightness relative to that 90° from sun. Full curves, theoretical for large smoke particles; dotted curve, theoretical for air molecules or smoke much smaller than the wave-length of light.

increases. If he retreats far enough the intensity of the interposed haze light will become so nearly equal to the intensity of the horizon sky light above the ridge that he will not be able to see the ridge. We here define clarity (c) or general visibility as the distance from an observer to a black ridge when it is just visible, or just not visible, i.e., at the limit, against the horizon sky. The side of the ridge toward the observer should be heavily timbered and in the shade; or at least the amount of light that goes from the ridge itself to the observer should be negligible compared with the haze light reaching him. Given a black ridge at such a distance from the observer that the haze light given by Eq. (1) ($i_0=0$ for a black ridge) is $1-k=96.8$ percent of the asymptotic haze light of the horizon; this distance is then the clarity. The intensity of asymptotic haze light (approximately horizon sky light) is s/a, found by setting x equal to infinity in Eq. (1). The intensity of the intervening haze light is $(1-e^{-ac})s/a$, found by setting x equal to c and $i_0=0$ in the same equation. By substituting these values of in-

[5] Nutting, Bull. Nat. Bur. Stand. **3**, 59–64 (1907).

tensity into Eq. (2) we get:

$$\frac{s/a-(1-e^{-ac})s/a}{s/a}=k.$$

This, solved for c, gives

$$c=(-\log_e k)/a. \tag{3}$$

This equation shows that clarity in miles is inversely proportional to the smoke density. A

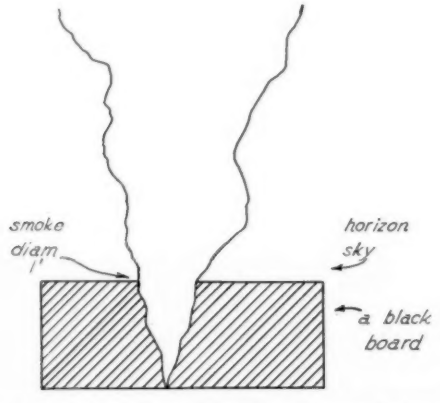


FIG. 2. A one-foot smoke. Black board just not distinguishable from sky where smoke is one foot in diameter.

logical name for the unit of smoke or haze density would be the elim (mile spelled backward). Elims are reciprocal miles of clarity. This equation also shows that while clarity depends upon a, it is independent of s, although a is related to s. This a is the same as Humphreys'[6] "extinction coefficient." If we adopt as our unit of intensity s/a and substitute Eq. (3) into Eq. (1) we get

$$i=1-k^{x/c}+i_0k^{x/c}. \tag{4}$$

SMALL SMOKE VISUAL RANGE

The visual range v of a small smoke column is the maximum distance it is visible against a dark background, through the haze. It is to be differentiated from c, clarity, and provides a more complicated problem. The base of such a smoke where it is most intense may be too small to be seen due to its distance, while the upper part where its size would permit it to be seen may be too highly attenuated. The resolving power of the eye is about one minute of arc. Two points subtending that angle at the eye can just be distinguished as two points, and a single object is not visible as having *area* if it subtends a lesser angle. A foot at a distance of one-half mile subtends an angle of approximately one minute of arc. In accordance with this value of the resolving power of the eye the part of a spreading smoke column that is less than one foot across could not be seen to have area (and thus not look like smoke) if it were 0.5 mile away. Therefore, d, the minimum diameter of smoke ever visible equals $x/(m/2)$ where m is the linear magnifying power of the binoculars used, if any, and x is the observer distance in miles. Thus

$$d=2x/m. \tag{5}$$

The standard smoke candles furnished us by the Forest Service gave a smoke that was mostly sublimed sulfur. A smoke column from one of these candles was of such density that a black board or cloth held with its upper edge just above the horizon and immediately behind the smoke (preferably on a smoky day)—refer to Fig. 2—could just not be seen through the smoke where the column was one foot in diameter. From this we see that our test smoke column where it is one foot in diameter is 96.8 percent as bright as the horizon sky. The above observations were made at times free from wind. Consistent results could not be obtained when

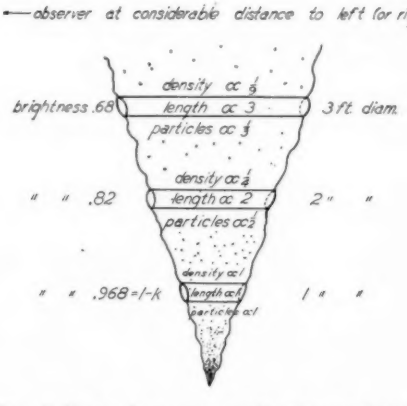


FIG. 3. For a given cross section the number of smoke particles is inversely proportional to diameter of smoke column. Above is a one-foot smoke.

[6] Humphreys, *Physics of the Air* (1929).

the wind was blowing. This should be kept in mind.

The brightness of the smoke column at various levels may be deduced from the following line of reasoning. Let r be the ratio of the brightness of a given smoke in a given direction as measured by a nearby observer, to the brightness of the same smoke with sunshine upon it and in the same direction, also measured by a nearby observer. ($r<1$ if during the first measurement of brightness the smoke is in the shade of some obstacle.) Let r' be the fraction of asymptotic brightness due to the number of smoke particles being less than infinity. Thus, the original smoke brightness is i_0 and is equal to rr'. Consider a cylinder through the smoke with its long axis parallel to the line of sight and with a unit cross section perpendicular to the line of sight. If the smoke is rising with uniform velocity, the smoke density in this cylinder is inversely proportional to the square of the diameter of the column at the level of the cylinder as shown in Fig. 3. Light coming from and through this cylinder will be equal in brightness to haze light that has come from and through a cylinder of haze of the same cross section and of such a length as to contain the same number of particles as are in the cylinder in the column. The relation between haze or smoke column brightness and the length of path that has produced it is given by Eq. (4), with i_0 set equal to zero. Of course, when used for smoke column brightness, c in this equation is really clarity with the observer inside the smoke column. For a one-foot smoke where it is one foot in diameter, c is, of course, one foot. Where it is d feet in diameter, c is d^2 feet. Setting $i_0=d$ in Eq. (4), the nearby brightness of the standard smoke column in sunlight where it is d feet in diameter equals

$$1-k^{d/d^2}=r'.$$

By using Eq. (5) this becomes

$$r'=1-k^{m/2x}=1-k^{m/2v}, \qquad (6)$$

when the small smoke is at the limiting distance of visibility through the haze. Stated in other words it is the brightness in sunlight that would be noted by a nearby observer, who views the light from the given level in the column before it has been modified to any significant degree by other particles that are dispersed through the air. If the smoke under observation is not a standard one-foot smoke, i.e., one whose diameter is one foot where its brightness is 96.8 percent of that of the horizon sky, but one with a width (diameter) of w feet where its brightness is 96.8 percent of that of horizon sky, its visual range with the unaided eye will be the same as that of a standard one-foot smoke viewed through w-power binoculars. This is true because binoculars do not change the relative brightness of areas, but only change the size. With 3-power binoculars a one-foot smoke will look just like a three-foot smoke to the unaided eye, when both observations are made in clear air. To make each smoke just disappear the same amount of haze must be interposed. From this it is seen that w and m, binocular magnifying power, play similar roles in our formulae. To make Eq. (6) applicable to all sizes of smokes observed with various degrees of magnification we write

$$r'=1-k^{mw/2v}. \qquad (7)$$

If a smoke column is at its limit of visibility its resultant brightness is, from Eq. (4),

$$i=1-k^{v/c}+i_0k^{v/c}.$$

If the smoke is against a dark timbered ridge, the brightness of its surrounding field, being due mostly to haze light, is $i=1-k^{v/c}$. Under these conditions the smoke just can be distinguished as a smoke according to Fechner's

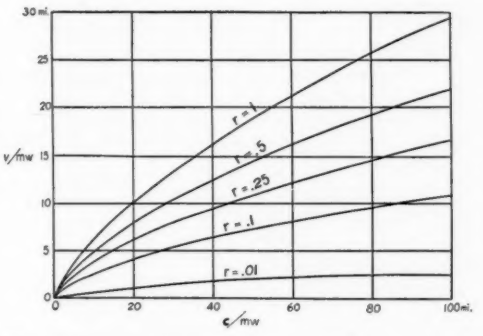


FIG. 4. One-foot smoke visual range (v) in terms of air clarity (c) for various ratios (r) of shade to sun brightness and various magnifying powers (m) and smoke sizes (w). $k=0.032$.

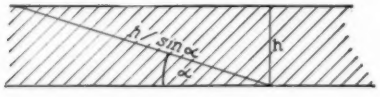


FIG. 5.

law when

$$1-k=\frac{1-k^{v/c}}{1-k^{v/c}+i_0k^{v/c}}.$$

Combining this with the relation $i_0=rr'$ and with Eq. (7) to eliminate r' we get

$$c/mw=\frac{-(v/mw)\log k}{\log\left[1+r(1-k^{mw/2v})(1-k)/k\right]}. \quad (8)$$

This is one of the two master equations that are developed in this investigation. It is plotted in Fig. 4 as a family of curves for various values of r as the parameter.

Above, the definition was made that

$$r=\frac{\text{brightness of a smoke column}}{\text{brightness of same smoke in sunlight}}.$$

An expression for this ratio is found by a consideration of the (1) illumination due to sunlight, coming through a uniform thickness of smoke, h, when the effective altitude of the sun is α, (2) brightness factor varying with the angle θ to the sun, and (3) sky brightness.

In terms of the absorption coefficient and the distance, x, through smoke that the sunlight has traveled, the illumination may be expressed as being proportional to

$$e^{-ax},$$

but from Eq. (3)

$a=-\log k/c$; also $x=h/\sin\alpha$ (see Fig. 5), so the illumination is proportional to

$$e^{(h\log k)/(c\sin\alpha)}.$$

Due to the curvature of the earth as can be seen from Fig. 6, α, the effective altitude of the sun, is somewhat greater than its actual measured altitude α'. When looking at the sun on the horizon one sees it through u miles of smoke instead of an infinite distance. In this position it has an altitude, relative to the slab of smoke $ABCD$, shown in Fig. 6, of ABC. Here $(AB)^2+(BE)^2=(AE)^2$ or $u^2+(4000)^2=(4002)^2$, as a good value of h was found from airplane flights to be 2 miles. This layer was observed to be rather uniform during the afternoon of cloudless days. Hence, $u=126$ miles and angle ABC is 2/126 radians$\fallingdotseq 1°$, a value that is to be added to the actual measured altitude of the sun when it is near the horizon, to obtain its effective altitude. Within the limits of the accuracy of this investigation it is safe to assume that this correction varies linearly with α', varying from 1° at $\alpha'=0°$ to 0° at $\alpha'=90°$. The correction of the sun's altitude because of the refraction is small enough to be neglected here; it is moreover of opposite sign to the above correction.

Since it can be seen from Fig. 1 that the brightness factor for particles larger than the wave-length of light is an exponential-looking function of θ (the angle in degrees measured by the observer from the smoke to the sun), we assume this factor is proportional to $e^{b\theta}$, where b is a constant, evaluated below.

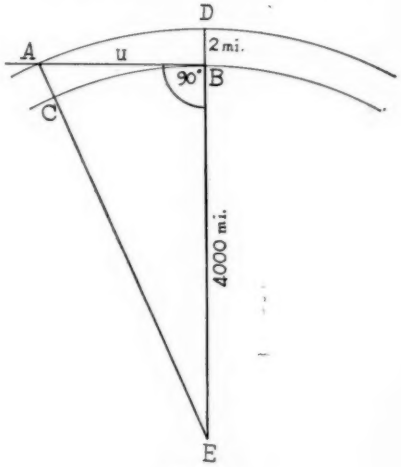


FIG. 6.

The resultant brightness of the smoke due to sunlight is proportional to the illumination (which, as has been shown, is proportional to $e^{(h\log k)/(c\sin\alpha)}$), and to the brightness factor $e^{b\theta}$. The brightness of the smoke due to the sky is sufficiently independent of the direction of horizontal vision that it may be called a constant, n. Accordingly then, the brightness of a smoke due to sun and sky is proportional to

$$e^{(h\log k)/(c\sin\alpha)}\cdot e^{b\theta}+n.$$

If the arbitrary reference of brightness be that at $\theta=90°$, this becomes

$$\frac{e^{[(h \log k)/(c \sin \alpha)]+b\theta}}{e^{[(h \log k)/(c \sin \alpha)]+b90}+n}. \qquad (9)$$

From experimental work shown in Fig. 1, when $\alpha=30°$, $c=20$ miles and $h=2$ miles, the haze brightness at $\theta=45°$ was measured to be 2.5, and at $\theta=0$ it was found to be 8.0 (by extrapolation). These values were obtained by pointing a hooded photo-cell at various regions of a cloudless sky at a constant altitude of 10° (the half-angle of vision through the tube). The hood was a round tube with a diaphragm at each end and at the middle, each diaphragm having a centered circular hole $\frac{1}{3}$ the inside diameter of the tube; the whole was painted flat black; no rays reflected from the walls of this tube can emerge from the other end unless reflected at least twice so it is a very black tube. By substituting these values in formula (9), two simultaneous equations in b and n are obtained. In solving these equations for b and n, a positive and a negative value of b result. The negative value is chosen since brightness must decrease as θ increases.

$$b=-0.0291; \qquad n=k^{0.2}/17.1.$$

From formula (9) and the definition of r

$$r=\frac{n}{e^{[(h \log k)/(c \sin \alpha)]+b\theta}+n}$$

$$=\frac{1}{1+17.1k^{[(h)/(c \sin \alpha)]-0.2}\cdot e^{-0.0291\theta}} \qquad (10)$$

and for $k=0.032$

$$r=\frac{1}{1-34.03e^{[(-3.442h)/(c \sin \alpha)]-0.0291\theta}}. \qquad (10a)$$

Considering r and θ as variables and h and $c \sin \alpha$ as independent parameters this equation can be plotted. Actually this treatment gives rise to a family of a family of curves, one family for each value of h. Fig. 7 is the plot of some of these families.

Equations (8) and (10) or their plots in Figs. 4 and 7 completely solve the problem of visibility of smoke columns viewed either with the naked eye or through binoculars of any power against a black background. A shaded slope covered with dark timber is in practice a near equivalent of a black background.

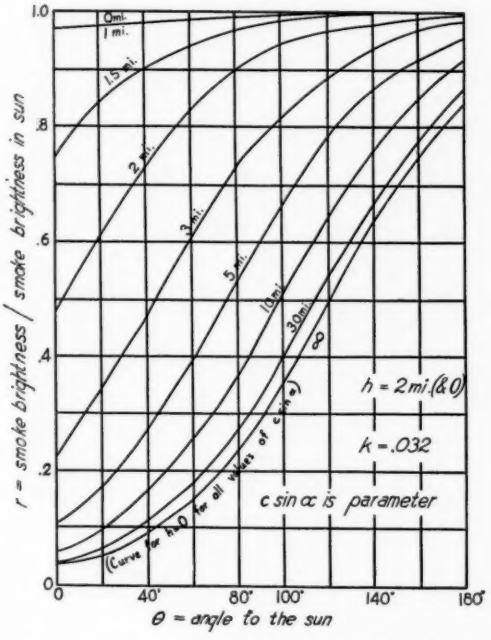


FIG. 7. r in terms of angle to sun and smoke and sun conditions.

v is to be found in terms of c, etc. from these two graphs. This method has been used to plot visibility graphs for small smokes for the Forest Service. It is of interest to observe that under certain conditions, adding smoke to all the air increases the visibility of a small smoke. This occurs when viewing, towards sunset, a small smoke on the shady side of a ridge with the haze all in the sunlight and with c approximately 3 to 5 miles. This can be seen by using Figs. 4 and 7 in succession, for $\theta=0$. The reason is that, in some cases, adding haze above the small smoke increases the relative small smoke illumination in the shade (compared with being unshaded by the ridge—there is little difference in illumination whether shaded or unshaded when there is thick haze) more than the added haze between the observer and the small smoke tends to obliterate the contrast. The case cited happens to be a very important one for forest fire lookouts.

It is important to note that c on a uniformly cloudy day has the same value as on a cloudless day if the smoke conditions are the same. This is true since the ratio of brightness of the haze light in front of the ridge to the brightness of the sky above it is independent of the amount of illumination, provided it is uniform. For the same reason, the visual range v of a smoke column is the same when in the sun on a cloudless day as it is when the sky is uniformly overcast with clouds, or just after sunset on a clear day, if the smoke density is the same. On a partly cloudy day, both v and c may vary with time and direction because of lack of uniform illumination.

Visibility Meter

The writers have constructed at least three types of visibility meters; *viz.*, the pinhole, the screen, and the binocular. The last and best of these three is discussed below.

Clarity, c, is the distance from which an observer views a distant dark ridge when it just fades into the horizon sky. Because of the small likelihood of a ridge being at this limiting distance, each time a determination may be desired, the meter here described was developed. This meter gives the ratio of the haze light in front of a dark ridge, at a known distance from the observer, to the infinite haze light of the horizon sky. Knowing this ratio and the actual ridge distance, then c, the distance the ridge would have to be from the observer to just disappear can be calculated. Actually the meter gives a factor which, multiplied by the actual ridge distance, gives c.

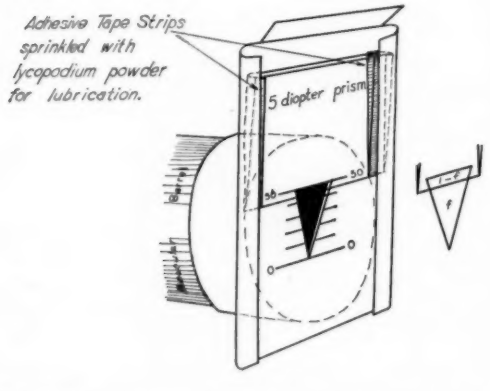


Fig. 8. Binocular-type visibility meter (old form). In diagram at right, $1-f$ and f are fractional areas.

Since the ratio of the haze light in front of a visible dark ridge to the horizon haze light is less than 0.968, a convenient way to make the ridge just disappear would be to add just enough light in equal and measured amounts to both the ridge haze and the sky light to make the ratio of the increased intensities equal to 0.968. It is best to add a fraction of horizon sky light itself, since this fraction is independent of sky brightness (not true for added artificial light on days of different brightness). In the binocular type meter this addition is effected by moving a wedge-type prism of say 0.5 diopter (deviation $=0.005$ radian$\doteqdot 3°$; angle$\doteqdot 0.5°$) down past a triangular aperture in a cover over one of the objectives of a binocular (the other objective is not used in a visibility determination) as in Fig. 8. In the first model the prism was mounted in ways and moved by hand down past the graduated aperture. In the latest model made according to our specifications by Leopold, Voelpel and Company of Portland, Oregon, the aperture attachment mounted on a pivot moves up past the edge of the prism. See Fig. 9. In use the motion proceeds until the upper of the two images of the ridgetop just disappears. The position is read on the scale. The scale reading is the factor by which the distance to the ridge is multiplied to give the clarity.

The calibration of the scale was accomplished in accordance with the following analysis. Let r' be the ratio of the ridge haze to horizon sky haze (essentially the same meaning of r' as above) and f the fraction of the aperture not covered by the prism when it is in the position to have made the upper image just not visible. For this position the total brightness just below the vanished ridge line is $0.968(1-k)$ of the total brightness just above it. If the value of the horizon sky brightness be the unit of brightness, the brightness of the ridge light will be $r'f$ due to the original image plus $1-f$ due to the added image, as shown in Fig. 10. The brightness just above the vanished ridge line is similarly f plus $1-f$ and accordingly 1 (since the decrease of sky light in the original image equals the

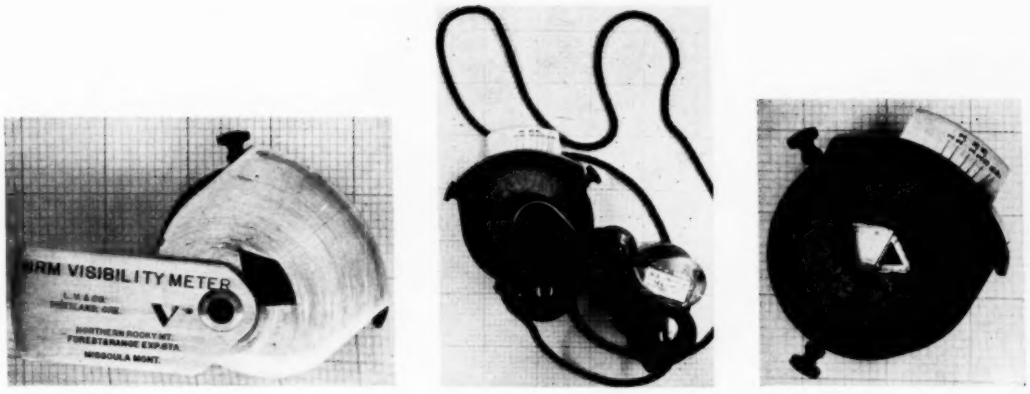


FIG. 9. The form of the meter finally adopted by the U. S. Forest Service in 1937.

increase of sky light in the added picture). Thus

$$0.968 = 1 - k = (r'f + 1 - f)/1,$$
$$r' = 1 - k/f. \tag{11}$$

But from Eq. (4)

$$r' = 1 - k^{x/c}. \tag{12}$$

Therefore

$$x/c = \log_k (k/f) = 1 + 0.668 \log_{10} f, \quad \text{for} \quad k = 0.032.$$

The value of f was calculated from the geometry of the aperture and the prism mounting for various positions on the scale. These values are plotted against x/c to give the lowest curve in Fig. 11. Simple values of x/c were then marked on the scale, their positions being evaluated from the curve. The reading of the scale for a setting is then the factor by which the actual ridge distance is multiplied to give the clarity.

It has been shown that if the smoke density is the same in all directions, c is the same in all directions. However, it is easier to find black ridges looking toward the sun, since the shady side of many are seen in that direction. Timbered ridges should be used, preferably those in the shade, and should be as distant as possible because it is desirable that as much of the light as possible (in the theory 100 percent was assumed) be haze light and not light from timber, etc. The reason the aperture over the objective is triangular (Fig. 8) and pointing down is to reduce diffraction blurring of the sky-ridge image. For instance in a former model the aperture had a long straight horizontal side at the bottom and the prism had to be moved almost to the bottom of the aperture before the original ridge disappeared (as with very little haze between us and ridge) and there was much vertical diffraction blurring of this original image because of the light for it coming through a narrow horizontal slit—k is much larger for a blurred edge than a sharp one. The reason the thin edge of the prism is pointed downward is to make the original image as clear as possible. In this arrangement it is the new image (lower) that gets its light through the prism and that therefore has the chromatic and any other blurring, but it is of no consequence if the new image is blurred because the other image is the one that is viewed. In designing this aperture it must be small enough so that its image at the eye-ring (exit pupil) of the binoculars is less than the size of the pupil of the eye (which should be placed at the eye-ring during the use of the

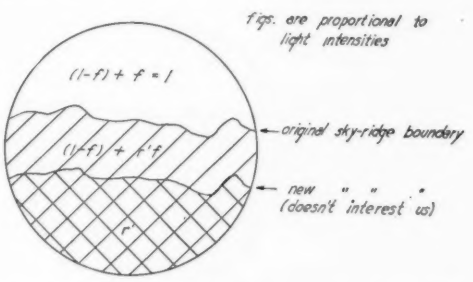


FIG. 10. View through the binocular of Figs. 8 and 9.

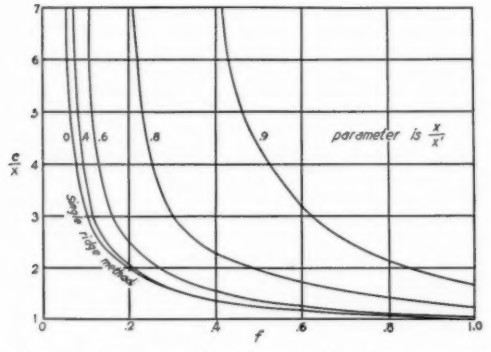


FIG. 11. Air clarity (c) *vs.* fraction (f) of lens uncovered by prism in Fig. 8 when upper ridge line in Fig. 10 of the nearer ridge just disappears. x is distance of nearer ridge and x' of farther ridge.

instrument). This is to insure all the light entering all parts of the aperture (both through the prism and below it) also entering the eye. Otherwise the ratio of light coming through and below the prism cannot be calculated from the prism position.

Method with cloudy horizon

On cloudy days (not part cloudy) if there is enough haze so that the horizon clouds are obliterated by it, the method given above can be used. However, if clouds are visible right down to the horizon the horizon sky light is variable and of no use as a reference. Nevertheless, on such days the meter can be used to make one ridge at a distance of x disappear against a more distant ridge at a distance of x' (instead of at infinity—horizon sky light). Thus, using the ideas back of Eq. (4), the ratio of haze brightness in front of the nearer black ridge to that of the farther equals $(1-k^{x/c})/(1-k^{x'/c})$ and this equals $1-k/f$ by Eq. (11). Thus

$$1-k/f=\frac{1-k^{x/c}}{1-k^{(x'/x)(x/c)}}. \qquad (13)$$

This is an equation in three variables—f, x/x' and c/x where c/x (essentially c) is the unknown. Visibility meter scale readings are essentially values of f. k, of course, is 0.032 as before. The equation is plotted in Fig. 11. Thus Fig. 11 when used with this visibility meter will give clarity by either the single or double ridge method. Naturally, when possible the former method is used. The fundamental equation corresponding to the figure is Eq. (13). Of course, the double ridge method includes the single ridge method. Thus, Eq. (12) is the simplified form of Eq. (13) for $x'=\infty$.

During the past fire-season, about 25 of these meters were apportioned to certain lookouts of District One, U. S. Forest Service. Fig. 9 shows photographs of this latest model.

CONCLUSIONS

In the present study of the visual range (v) of a small smoke column, consideration has been given to the six independent variables, (h) height of smoke layer, (α) altitude of the sun, (θ) angle between the smoke column and the sun, (w) size of the smoke, (m) power of binoculars, (c) air clarity (which is inversely proportional to the smoke density), that are important under the conditions for which this study was made. A more general study would necessitate a consideration of the brightness, the hue and the saturation of the background. For color, however, Middleton[7] has shown that "the visual range of an object of any color is very nearly identical with that of a grey object of the same brightness factor; thus, there is no need for a special theory of the visual range of colored objects." A visibility meter has been described which measures the distance a small smoke should be visible.

In conclusion the authors wish to express their appreciation of the sympathetic support and constructive suggestions of the late Mr. Lloyd G. Hornby and of Mr. Harry T. Gisborne who were successively in charge of the investigation for the Northern Rocky Mountain Forest and Range Experiment Station of the U. S. Forest Service. Thanks are also due Ruth Leib Evenson who did much of the computing.

[7] Middleton, Trans. Roy. Soc. Can. *3rd* series, Sec. **3**, **29**, 127 (1935).

The Frederic Ives Medal for 1939

Awarded by The Optical Society of America to August Herman Pfund,
Professor of Physics at The Johns Hopkins University,
for distinguished work in optics.

This medal, awarded biennially, was endowed in 1928 in honor of Frederic Ives, distinguished for his pioneer contributions to color photography, photoengraving, three-color process printing, and other branches of applied optics.

Dr. August Herman Pfund

Doctor August Herman Pfund

IVES MEDALIST FOR 1939

AT its Lake Placid meeting in October, 1939, the Optical Society of America awarded the Frederic Ives Medal to Dr. A. H. Pfund, Professor of Physics at The Johns Hopkins University. This medal is awarded biennially for distinguished work in optics, and its past recipients have been as follows:

In 1929, Edward Leamington Nichols;
In 1931, Theodore Lyman;
In 1933, Robert Williams Wood;
In 1935, George Ellery Hale;
In 1937, Herbert Eugene Ives.

The presentation of the medal to Dr. Pfund took place at the Annual Dinner of the Society, which was held in the Lake Placid Club, with nearly one hundred members and guests of the society attending.

Presenting Dr. Pfund, the chairman of the committee appointed to nominate a candidate for the award spoke as follows:

"Born in Madison, Wisconsin, December 28, 1879, Mr. Pfund attended the public schools of Madison and the University of Wisconsin, from which he received his B.S. degree in 1901. Two years were spent as a graduate student at that institution. He then went to The Johns Hopkins University where he received his Ph.D. degree in 1906. He has been located there continuously since. In succession he has been Carnegie Research Assistant, Assistant in Physics, Johnston Scholar, Associate in Physics, Associate Professor and since 1927 Professor of Physics. He was awarded the Science Club Medal at the University of Wisconsin in 1901; The Edward Longstreth Medal by the Franklin Institute in 1922 for originality and ingenuity in applying physical methods of precision in the paint industry and for his inventions embodied in his colorimeter, cryptometer, paint film gauge, and rotating sector; and the Charles B. Dudley Medal by the American Society for Testing Materials in 1931 for a paper of outstanding merit as an original contribution on research on engineering materials. The paper in question related to paints and was entitled 'Hiding Power Measurements in Theory and Application.'

"Dr. Pfund's scientific contributions total 63 published papers. Of these, 52 contain essentially new matter. A survey of his contributions shows twelve items which may be considered as the bases for this award. (Numbers in parentheses at the end of each numbered paragraph refer to papers in the appended 'List of Publications.')

"(1) Dr. Pfund discovered two of the three characteristic vibration frequencies of crystals. In a study of 'Polarization and Selective Reflection in the Infrared Spectrum,' he found that the nitrates of Mg, Co, NH_4, Ca, all molten, and of Ag and K, both solid, possessed reflectivity maxima at or close to 7.45μ and that the sulphates of Ni, Co, Cu, Cd, Fe, Na and K, all solid, possessed reflectivity maxima at or near 9.05μ. These results showed that certain, at least, of the vibration frequencies characteristic of nonmetallic crystals are associated with their intramolecular structures. From a somewhat similar study in the ultraviolet, a second, the characteristic electronic frequency was found. The third, a lattice frequency, was found by Rubens. (2, 27)

"(2) He developed the selenium polarizer and analyzer, which is particularly valuable because of its uniform high reflectivity throughout the entire infra-red. This occurred in connection with the study just mentioned which resulted in the discovery of the infra-red characteristic frequency of a crystal. (2)

"(3) In his thermoelectric study of stellar radiation, he developed a thermopile-galvanometer combination which taken in conjunction with the telescope with which it was used was capable of detecting the radiation from a candle at the distance of 18 miles. (8)

"(4) Making use of the well-known high reflectivity of metals in the infra-red and the relatively high transparency of a thin film of gold in the visible, he invented the 'gold goggles' which are used for protecting the eyes of welders, glass workers, and others from overdoses of infra-red.

"(5) He discovered the resistance-light sensitivity of cuprous oxide and with it the differential

effect which is dependent on whether the illumination of the cell used is 'front' or 'back' illumination. (13)

"(6) To the series of hydrogen lines discovered by Lyman, Balmer, Paschen, and Brackett, he added the first line of a new similar series. Corresponding to a shift of an electron, in the x-ray terminology, from a *P* to an *O* level, a line which he found at 7.40μ is considered in good agreement, in view of experimental difficulties, with the computed 7.46μ. (20)

"(7) He developed and described the construction and mode of operation of the standard iron arc which is generally used in spectroscopy. (3)

"(8) By the introduction of Welsbach mantle material into the arc discharge between terminals connected to the secondary of a high potential transformer, he overcame the well-known weakness of emission in the near infra-red of the Welsbach mantle as ordinarily operated. He made of the mantle not only a rival of the Nernst filament for the near infra-red, but a source for the whole of the infra-red. (44)

"(9) He discovered for quartz and calcite, a new type of transmission band on the short wave-length sides of their regions of metallic reflection in the infra-red. In this work, he used coarse powder films formed of particles about 5μ in diameter. Such transmission bands have their maxima in the regions where the refractive indices are near unity and the reflectivities very small. These transmission bands for coarse particles seem therefore 'limited on the short wave-length side by the copious reflection from coarse particles and on the long wave-length side by the true absorption band.' (37)

"(10) For powder filters in the infra-red, he found that the wave-length at which the film becomes highly transparent is roughly twice that at which it may be said to cease being relatively opaque. Filters with these characteristics are found very valuable in the elimination of overlapping spectra when an echelette grating is used. (31, 33, 37)

"(11) He discovered that metallic blacks may be obtained by vaporizing metals in air or in hydrogen at pressures ranging from 0.5 mm Hg to 3 mm Hg. Blacks from Au, Ag, Ni, Cu, Zn, Cd, Pb, Bi, Sb, Se, and Te have been obtained by this method. Of these Zn black seems to be most highly absorbent throughout a great range of the spectrum. Where the electrolytic method of producing a platinum or a nickel black is inadvisable because of the delicacy of the apparatus, a zinc black produced by this method may prove to be both safe and suitable. (30)

"(12) From a study presented at the Niagara Falls meeting in 1938 of the peculiar mosaics formed by powdered pigments, he has found it possible to measure particle size, particle distribution and refractive index for finely divided pigments. Particle sizes of the order of 0.2μ have been measured by this method." (48)

In making the award, President R. C. Gibbs said: "Professor Pfund, on behalf of the Optical Society of America, and *in recognition of your many original discoveries in the field of experimental optics, particularly in the study of infra-red radiation*, as cited by the Committee, it is my pleasure and privilege officially to award to you and to present to you the Society's Frederic Ives Medal for 1939."

Dr. Pfund, acknowledging the award, replied: "Mr. President, Dr. Worthing, Members of the Optical Society and Honored Guests: Upon having been awarded the Frederic Ives Medal by the Optical Society of America I feel that this is quite the proudest moment of my life. So far as I am concerned, my cup of happiness is full.

"In reflecting on these festivities I realize that I have known three generations of the Ives family. The son, Herbert, and I were room-mates while fellow students at The Johns Hopkins University. Through him, it was my privilege to meet his father, Mr. Frederic Ives in whose honor this medal has been struck. Mr. Ives was a quiet, unassuming man—yet one who was ablaze with enthusiasm for his work. In his life he suffered cruel disappointments. These, however, were without effect on his enthusiasm. Men such as he have rediscovered the fount of eternal youth. To him, life was an exciting adventure to the very end. What more can any man ask of life?"

A. G. WORTHING
Chairman, Committee on Award of the Frederic Ives Medal for 1939

Scientific Contributions of August Herman Pfund

(Brief published abstracts of papers later published in full, are not listed.)

1. A Study of the Selenium Cell. Phil. Mag. **7** (6), 26 (1904).
2. Polarization and Selective Reflection in the Infrared Spectrum. Astrophys. J. **24**, 19 (1906).
3. Metallic Arcs for Spectroscopic Investigations. Astrophys. J. **27**, 296 and 299 (1908).
4. A Redetermination of Wave-lengths of Standard Iron Lines. Astrophys. J. **28**, 197 (1908).
5. The Electrical and Optical Properties of Metallic Selenium. Phys. Rev. **28**, 324 (1909).
6. A New Method for Producing Ripples. Phys. Rev. **32**, 324 (1911).
7. Application of the Selenium Cell to Photometry. Phys. Rev. **34**, 370 (1912).
8. Thermo-electric Measurements of Stellar Radiation. Publications of Allegheny Observatory **3**, 43 (1913).
9. Durch teilweise versilberte Platten erzeugte Interferenzstreifen u. Absorptionsspektra im nahen Ultrarot. Zeits. f. Wiss. Phot. **12**, 341 (1913).
10. An Improved Mercury Lamp. Phys. Rev. **3**, 314 (1914).
11. A Contrast-Equality Photometer. Phys. Rev. **4**, 477 (1914).
12. The Use of the Rotating Sector in Photometry. Psych. Rev. **21**, 116 (1914).
13. The Light Sensitiveness of Copper Oxide. Phys. Rev. **7**, 289 (1916).
14. The Colors of Mother of Pearl. J. Frank. Inst. **183**, 453 (1917).
15. Reflection Factors of Tungsten at Incandescent Temperatures (with W. Weniger). Phys. Rev. **14**, 427 (1919).
16. The Colorimetry of Nearly-White Surfaces. J. Frank. Inst. **189**, 371 (1920).
17. An Extension of the Range of the McLeod Gauge. Phys. Rev. **18**, 78 (1921).
18. A Precision Rotating Sector: Aperture Variable and Measurable while in Motion. J. Frank. Inst. **193**, 641 (1922).
19. Optical Properties of White Paint Pigments in the Ultra-Violet Spectrum. Proc. A.S.T.M. **23**, 369 (1923).
20. The Emission of Nitrogen and Hydrogen in the Infrared. J. Opt. Soc. Am. **9**, 193 (1924).
21. Intensities and Reflecting Powers in the Lyman Region of the Hydrogen Spectrum. J. Opt. Soc. Am. **12**, 467 (1926).
22. An Infrared Spectrometer of Large Aperture. J. Opt. Soc. Am. **14**, 337 (1927).
23. Shift in Infrared Reflection Maxima with Temperature. J. Opt. Soc. Am. **15**, 69 (1927).
24. Windows and Actinometers for Heliotherapy. Bull. Johns Hopkins Hospital **40**, 228 (1927).
25. A Relative Method for Determining Particle-size of Pigments. Ind. Eng. Chem. **19**, 51 (1927).
26. A Practical Window for Transmitting Ultra-Violet Light. J. Am. Med. Assoc. **91**, 18 (1928).
27. Metallic Reflection from Rock-Salt and Sylvite in the Far Ultra-Violet. Phys. Rev. **32**, 39 (1928).
28. A Study of the Action of Light of Different Wavelengths on Nitrocellulose (with H. B. Devore and V. Cofman). J. Phys. Chem. **33**, 1836 (1929).
29. The Measurement of Gloss. J. Opt. Soc. Am. **20**, 23 (1930).
30. Bismuth Black. Rev. Sci. Inst. **1**, 397 (1930).
31. Infrared Filters of Controllable Transmission. Phys. Rev. **36**, 71 (1930).
32. A Plane-Parallel Plate Refractometer. J. Opt. Soc. Am. **21**, 182 (1931).
33. Absorption of Infrared Radiation by Small Particles. Phys. Rev. **39**, 64 (1932).
34. A Filter for the Study of the Raman Effect. Phys. Rev. **42**, 581 (1932).
35. A Universal Spectrometer for the Infrared. J. Opt. Soc. Am. **22**, 281 (1932).
36. Infrared Radiations from Small Particles. J. Opt. Soc. Am. **23**, 270 (1933).
37. Optical Properties of Metallic and Crystalline Powders. J. Opt. Soc. Am. **23**, 375 (1933).
38. An Interference Scheme for Measuring the Cell Depth of a Siedentopf Ultramicroscopic Counting Chamber (with D. L. Gamble). J. Opt. Soc. Am. **23**, 416 (1933).
39. Highly Reflecting Films of Zinc Sulphide. J. Opt. Soc. Am. **24**, 99 (1934).
40. Anomalous Dispersion by Diffraction. J. Opt. Soc. Am. **24**, 121 (1934).
41. Rayleigh's Law of Scattering in the Infrared. J. Opt. Soc. Am. **24**, 143 (1934).
42. The Dispersion of CS_2 and CCl_4 in the Infrared. J. Opt. Soc. Am. **25**, 351 (1935).
43. Surface Tension Measurements of Viscous Liquids. Ind. Eng. Chem. (Analytical Edition) **8**, 81 (1936).
44. The Electric Welsbach Lamp. J. Opt. Soc. Am. **26**, 439 (1936).
45. A Polaroid Half-Shade Analyzer. J. Opt. Soc. Am. **26**, 453 (1936).
46. Radiation Thermopiles. Rev. Sci. Inst. **8**, 417 (1937).
47. Apparatus for the Study of the Raman Effect. J. Opt. Soc. Am. **28**, 264 (1938).
48. The Colors of Mosaic Powder Films. J. Opt. Soc. Am. **29**, 10 (1939).
49. Transparent and Opaque Screens for the Near Infra-Red. J. Opt. Soc. Am. **29**, 56 (1939).
50. Refractive Index of a Glass Plate by Multiple Reflections. Am. Phys. Teacher **7**, 193 (1939).
51. The Dispersion and Transmission of Methyl Methacrylate Polymer. J. Opt. Soc. Am. **29**, 291 (1939).
52. Atmospheric Contamination—an Infrared Study Without the Use of a Spectroscope. Science **90**, 326 (1939).